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FUMIGATION OF CATTLEYA ORCHIDS WITH HYDROCYANIC-ACID GAS

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INTRODUCTION

As a preliminary, it will not be out of place to refer briefly to the regulations of the Federal Horticultural Board governing the importation of orchids prior to the adoption of fumigation with hydrocyanic-acid gas as a requirement for entry. These plants, which for the most part originate in countries that do not maintain a recognized inspection service, were allowed to enter under permit through designated ports of entry which were provided with Federal inspectors, or collaborators of the Federal Horticultural Board. Orchids arriving in the ports designated were examined by representatives of the board, and, if found to be free from insects and diseases believed to be injurious, were liberated from customs and allowed to proceed to the consignee.

INSECT PESTS INTERCEPTED

A total of 137 species of insects were collected on imported orchids, principally species of Cattleya, or in cases containing them, from August, 1912, to December 16, 1917, including 41 species of scale insects and a number of recently introduced ants which are now firmly established and responsible for considerable injury in greenhouses as far west as Indiana. A careful examination of three cases of Colombian orchids by the junior author revealed the presence of 17 species of insects distributed in the following orders: Orthoptera, Hymenoptera, Hemiptera, Coleoptera, Lepidoptera, Corrodentia, and Collembola.

Early in the spring of 1917 a shipment of 47 cases of cattleyas from Colombia was found, upon examination by Messrs. H. B. Shaw and D. G. Tower, of the Federal Horticultural Board, to be infested with larvæ of an unrecognized pyralid moth not known to occur in the United States. Inasmuch as these larvæ were present in numbers on and among the roots of the plants, the writers were instructed by the Federal Horticultural Board to conduct experiments immediately to determine the possibility of killing these larvæ and other insects by the vacuum process without removing the plants from the original container.

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EXPERIMENTS TO DETERMINE THE POSSIBILITY OF KILLING INSECTS BY FUMIGATION WITHOUT REMOVING THE PLANTS FROM THE CONTAINER

To determine the effectiveness of this method of fumigating, the insects and plants were exposed to the gas under conditions comparable to those existing at commercial vacuum fumigation plants, where time would not permit the removal of the plants from the containers. To obtain this result, pyralid larvæ were fumigated as follows: Two in a vial plugged with cotton; two secreted in the roots of a cattleya wrapped in one thickness of newapaper; two secreted in the roots of a cattleya wrapped in cardboard and three thicknesses of newspaper; one in a vial plugged with cotton and wrapped with plant in two thicknesses of manila paper; two in nests of two and three pill boxes,[1] respectively.

The containers were placed in the fumigation chamber, the door closed, and a 20-inch vacuum produced. The gas was then generated, a dosage of 1 ounce of sodium cyanid[2] per 100 cubic feet of space being given, with an exposure of 40 minutes as follows: Five minutes were allowed for full generation and then 5 minutes to wash all the gas over to the fumigation chamber, after which the plants and insects were exposed to the gas for 30 minutes under normal atmospheric conditions. At the completion of the exposure the gas was removed from the fumigation chamber by producing a 25-inch vacuum. Upon examination all larvæ were found dead, irrespecive of their position, some being flattened out and void of viscera.

To determine further the penetration of hydrocyanic-acid gas under vacuum conditions, the following test was conducted with the black-walnut worm (*Datana integerrima* Grote and Robinson). This experiment differed slightly from the former in that the exposure was increased to one hour with a preliminary vacuum of 26 inches. The dosage remained the same, the larvæ being exposed to the gas under the following conditions: (1) Eight larvæ in a nest of triple pill boxes, inclosed in two tight-fitting cardboard coccid boxes,[3] the outer, or larger, box being wrapped with four thicknesses of dry newspaper and one layer of heavy wrapping paper and tied. This package was then placed in a wheat sack which was inclosed in a mail bag. (2) Four larvæ were similarly wrapped, except that the newspaper was thoroughly wet. (3) Four larvæ in triple pill boxes were inclosed in a tight-fitting screw-top mailing tube and placed in a thin seed sack within a wheat sack. (4) Same conditions as No. 3, except that the mailing tube was wrapped in six layers of wet newspaper. Upon completion of the exposure all larvæ were dead, whereas all larvæ similarly wrapped and held as controls were alive.

[1] Diameter of pill boxes as follows: 1¾, 1½, and 1¼ inches.

[2] Sodium cyanid guaranteed to contain not less than 51 per cent cyanogen and commercial sulphuric acid (about 1.84 sp. gr., or 66° Baumé) were used in all experiments referred to in this paper.

[3] These boxes measured 5 by 3 by 2 and 3 by 2 by 1½ inches.

EXPERIMENTS TO DETERMINE EFFECT OF FUMIGATION ON IMPORTED CATTLEYAS AT TIME OF ARRIVAL

A series of experiments under vacuum and normal atmospheric conditions was conducted to determine what effect, if any, the gas would have on the leaves, pseudobulbs, and general health of the plant. Mechanically injured and sound plants were purposely fumigated with excessive dosages to determine the appearance of fumigation injury. To induce burning, the leaves were slashed and bruised with a hatchet. Leaves so treated invariably exhibited blackened areas immediately around the injured spot, and yellowing was evident where the food supply was cut off. This yellowing, however, was no more pronounced in the fumigated plant than in the unfumigated ones, and was invariably confined to the old or injured leaves. The experience of the writers with the introductions of the Department of Agriculture has been that leaves on plants which have been poorly ventilated for a long period slowly turn yellow and eventually fall when exposed to the air. These leaves are apparently devitalized by abnormal shipping conditions, and the discoloration may be due to physiological changes.

To demonstrate that fumigation is not responsible for the shedding of all the leaves which are frequently found in containers when delivered to the consignee a number of cases were carefully examined at the port of entry. Two poorly ventilated cases yielded the following count: (1) Number of plants, 42; total number of leaves, 304, of which 234, or 76 per cent, had fallen from the plants and were in various stages of decay (Pl. 20). (2) Number of plants, 69; number of pseudobulbs on the plants, 719, of which 194 were dead; total number of leaves, 539, of which 257, or 47 per cent, were dead. These figures represent fairly well the condition of poorly packed orchids at the time of arrival, although there are several instances on record where the entire contents of the case were dead.

Orchids fumigated in New York on May 27, together with controls, were forwarded to Washington and held in a greenhouse. On July 30 both the fumigated and unfumigated plants had lost 33 per cent of their old leaves. As further evidence that fumigation with 1 ounce of sodium cyanid does not kill the plants, if they are in a reasonably good condition at the time of fumigation, a commercial orchid grower, on July 17, had cut 80 blooms from 700 plants of *Cattleya trianae* which were fumigated in New York during the latter part of May. It is apparent, therefore, that injury and shedding of leaves which might be attributed to fumigation at the port of entry are in a large measure due to poor packing, improper ventilation, and poor shipping conditions. This conclusion is further supported by the summarized experiments given in Tables I, II, and III.

TABLE I.—*Results of fumigation of cattleyas immediately upon arrival at Washington, D. C., under summer temperature conditions*

Dosage rate, in ounces of sodium cyanid.	Exposure.	Temperature.	Vacuum.	Conditions under which fumigated.	Number of leaves on— Date of fumigation, June 6, 1917.	Number of leaves on— June 25, 1917.	Number of leaves on— Nov. 22, 1917. New.	Number of leaves on— Nov. 22, 1917. Old.	Number of old leaves lost since fumigation. June 6–25.	Number of old leaves lost since fumigation. June 25 to Nov. 22.	Condition on Nov. 22, 1917. Buds or shoots.	Condition on Nov. 22, 1917. Flowers.	Condition on Nov. 22, 1917. Plants.	Percentage of old leaves lost after fumigation.
	Hrs.	*°F*	*In.*											
1	1	80	20	Thoroughly wet.	77 on 12 plants.	62	28	33	16	29	[a] 25	5	3 excellent, 7 good, 2 fair.	61
1	1	80	20	Dry	101 on 12 plants.	88	31	76	15	12	[b] 23	4	4 excellent, 4 good, 4 fair.	25
1	1	80	20	Thoroughly wet.	76 on 10 plants.	36	16	22	40	14	19	0	Poor before fumigation; 1 excellent, 2 good, 7 fair.	71
1	1	80	20	Dry	41 on 7 plants	20	12	15	21	5	[c] 8	0	Poor before fumigation; 3 good, 2 poor, 2 missing.	64
2	½	80	20	Wet	69 on 12 plants	54	24	38	15	16	[d] 9	5	5 good, 5 poor, 2 missing.	70
2	½	80	20	Dry	65 on 13 plants	30	16	27	35	3	[e] 21	0	1 excellent, 1 good, 1 poor, 2 missing.	88
4	⅔	80	25	do	61 on 4 plants	32	14	20	29	12	2	2	Good, although 1 plant lost 15 pseudobulbs.	69
Control					35 on 9 plants	25	2	21	10	4	6	0	Good; pseudobulbs not counted.	40

[a] Ten growing. [b] Eleven growing. [c] One poor. [d] Four growing. [e] Fourteen growing.

TABLE II.—*Summary of experiments to determine penetration and effect of hydrocyanic-acid gas on cattleyas held unplanted for one month prior to fumigation. All box fumigations were conducted under normal atmospheric conditions*

Number of plants.	Treatment before, during, and after fumigation.	Rate in ounces of sodium cyanid.	Exposure.	Vacuum.	Temperature.	Relative humidity.	Number, when fumigated July 30, 1917, of— Leaves.	Number, when fumigated July 30, 1917, of— Shoots.	Number, when fumigated July 30, 1917, of— Buds.	Number, when fumigated July 30, 1917, of— Pseudobulbs.	Number, Nov. 22, 1917, of— Leaves. Old.	Number, Nov. 22, 1917, of— Leaves. New.	Number, Nov. 22, 1917, of— Pseudobulbs. Old.	Number, Nov. 22, 1917, of— Pseudobulbs. New.	Number, Nov. 22, 1917, of— Buds.	Number, Nov. 22, 1917, of— Flowers.	Percentage of old leaves lost after fumigation.
			Hrs.	*In.*	*°F.*	*Pct.*											
3	Dry, wrapped 2 hours before fumigation and kept wrapped 24 hours after fumigation	1	1	26	90	60	13	5	0	[a] 32	11	1	29	1	6	1	15
4	Same as above, except wet	1	1	26	90	60	10	3	1	31	6	5	29	6	2	0	40
3	Same as above, except dry	1½	1	26	90	60	10	3	2	26	6	4	26	4	7	0	40
3	Same as above, except wet	1½	1	26	90	60	11	1	3	[b] 37	9	4	27	4	7	0	18
3	Dry, held in dark 2 hours prior to fumigation; not wrapped when fumigated	1½	1	([c])	90	60	11	2	0	23	11	8	18	8	4	0	0
1	Wrapped in heavy paper 2 hours before fumigation and kept wrapped 24 hours	4	1	26	86	65	8	3	0	18	1	3	1	3	2	1	87
3	Same as above, except wet	4	1	26	86	65	11	3	1	20	2	0	10	0	3	0	81
1	Under canvas 2 hours before fumigation; not wrapped when fumigated	4	1	([c])	86	65	6	5	0	24	4	3	24	3	1	0	33½
4	Control						17	8	0	32	14	3	28	3	4	2	17½

[a] Six in poor condition. [b] Eight scarred. [c] In box.

TABLE III.—*Results of experiments similar to those given in Table I, except that all plants fumigated were previously fumigated in New York City on May 27, 1917, with 1 ounce of sodium cyanid per 100 cubic feet, with an exposure of 40 minutes under partial vacuum as described in the text*

Number of plants.	Treatment before, during, and after fumigation.	Rate in ounces of sodium cyanid.	Exposure.	Vacuum.	Temperature.	Relative humidity.	Number, second fumigation, July 30, 1917, of— Leaves.	Shoots.	Buds.	Pseudobulbs.	Number, November 22, 1917, of— Leaves. Old.	Leaves. New.	Pseudobulbs. Old.	Pseudobulbs. New.	Buds.	Flowers.	Percentage of old leaves lost after fumigation.
			Hr	*In.*	°*F*	*Pc*											
7	Wrapped 2 hours before fumigation and kept wrapped 24 hours	1	1	26	90	60	17	5	2	[a]56	11	4	49	10	10	1	35
7	Same as above, except wet	1	1	26	90	60	24	8	3	54	11	1	46	1	15	0	54
2	Same as above, except dry	1½	1	26	90	60	12	9	0	[b]48	1	6	45	5	9	0	91⅔
5	Same as above, except wet	1½	1	26	90	60	19	9	1	73	10	8	72	8	14	0	47
4	Wet, held in dark 2 hours prior to fumigation; not wrapped when fumigated	1½	1	(c)	90	60	16	8	0	37	13	7	34	6	4	0	18½
5	Control						28	8	0	46	23	8	41	7	7	1	17½

[a] Three in poor condition. [b] Five black. [c] In box.

All plants used in the experiments recorded in the tables were selected at random, effort being made in so far as possible to equalize the number of leaves and pseudobulbs in each test. Moreover, it was discovered after the plants bloomed that four species of Cattleya were represented—viz, *trianae*, *mossiae*, *schroederae*, and *percivaliana*. Unfamiliarity with these plants rendered it impossible for the writers to separate the different species by the characters of the pseudobulbs and leaves. So far as the different varieties were concerned, however, there was no noticeable difference in the final results. Of 116 plants fumigated, only 8, or approximately 7 per cent, died.

As indicated in the tables, the plants were fumigated under unfavorable conditions as regards temperature and moisture. This was deemed advisable, since orchids are offered for entry in large numbers during the summer months, and at this season it is frequently impossible to work with low temperatures; and, furthermore, these plants occasionally are drenched with water *en route*.

All plants listed in Table III received two fumigations, the first exposure being in New York on May 27, with sodium cyanid at the rate of 1 ounce per 100 cubic feet of space, with an exposure of 40 minutes and a preliminary 20-inch vacuum.

All plants used were grown by Dr. James S. Cannon, the orchid expert of the propagating gardens of the War Department, and in many cases were not potted for weeks after fumigation. It is evident, therefore, that the cattleyas were not given special treatment, but were handled as a commercial shipment.

The percentage of old leaves lost, as given in the tables, is neither distinctly correlated with conditions under which the plants were fumigated nor with the dosage given. Whether this discrepancy is due to specific resistance of the different species of Cattleya fumigated or to physiological conditions of the plants at the time of fumigation remains to be determined by the use of known plants kept under similar conditions before exposure to the gas. It will be noted, however, that plants which lost a high percentage of old leaves produced flowers, new leaves, and pseudobulbs. (Pl. 19.)

FUMIGATION AS A REQUIREMENT FOR ENTRY

Owing to the large number of insects which have been intercepted in cases of orchids and to extremely poor inspection facilities at the ports of entry, the Federal Horticultural Board has instructed its inspectors to require the fumigation of all orchids arriving in bulk from countries which do not maintain a recognized inspection service. On the strength of the experiments listed in this paper, all plants fumigated in the original container must be fumigated with 1 ounce of sodium cyanid, with an exposure of one hour. A preliminary vacuum of 20 inches is required prior to the generation of the gas.

CONCLUSIONS

(1) Black areas appear on unfumigated as well as fumigated leaves which have been injured.

(2) Progressive yellowing occurs on both unfumigated and fumigated plants and depends on adverse treatment or age of the leaves.

(3) Fumigated plants lose their leaves more rapidly than do unfumigated plants when subjected to adverse treatment. Young leaves and shoots are not severely injured by the gas with a 1-ounce dosage, although a number of old devitalized leaves may fall.

(4) Fumigation is not responsible for dying of pseudobulbs, if excessive dosages are not used.

(5) Presence of water on cattleya leaves does not increase burning from fumigation.

(6) Loss of a few old leaves does not render a plant valueless, as in a brief period they are replaced by new vigorous foliage.

(7) Where excessive dosages are not employed, orchids are apparently stimulated by hydrocyanic-acid gas. (See Pl. 19.)

(8) Infested orchids at the time of arrival at the port of entry, if in a reasonably good condition, are not seriously affected by hydrocyanic-acid gas generated at the rate of 1 ounce of sodium cyanid per 100 cubic feet, and are not killed where a 4-ounce dosage is used.

(9) Insects which are not hermetically sealed in stems or pseudobulbs of cattleyas can be killed in the original cases with hydrocyanic-acid gas, provided a preliminary 20-inch vacuum is given.

PLATE 19

Cattleya schroederae five months after having been fumigated with hydrocyanic-acid gas at the rate of 1 ounce per 100 cubic feet of space.

PLATE 20

Examining a case of cattleyas before fumigation at the port of New York. This case yielded the following count: Number of plants, 42; total number of leaves, 304; number of leaves off of the plants in various stages of decay, 234.

NET ENERGY VALUES OF ALFALFA HAY AND OF STARCH

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COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

The experiments here reported were undertaken primarily to determine the net energy value of starch as a representative of the carbohydrates. Alfalfa hay was used as the necessary roughage chiefly in order to secure a mixed ration not too low relatively in protein, but in part also for the sake of comparison with the results of several earlier determinations on the same feeding stuff.

OUTLINE OF EXPERIMENT

The subject of the experiment was a pure-bred Shorthorn steer, designated as Steer J, bred by The Pennsylvania State College. He was a year and 10 months old at the beginning of the experiment and had been chiefly grass fed up to that time. He was the same animal used in the subsequent year for the experiment on the influence of the degree of fatness of cattle upon their utilization of feed already reported.[1]

The general plan of the experiment was the same which has been employed in our more recent determinations of the net energy values of concentrates. It consisted, first, in determining with the aid of the respiration calorimeter, the net energy value of the roughage by a comparison of two or more periods in which different amounts of it were fed and second, in making similar determinations upon a mixture of hay and starch in the proportion of 2.5 to 1. By a difference calculation, precisely similar in principle to that commonly used in estimating the digestibility of a concentrate, the net energy of the starch could then be computed.[2] As a matter of fact, the trials were not actually made in this order, those on the mixed ration preceding those on the hay.

It may be noted that this method differs from that employed by Kellner, who has also reported a number of determinations of the net energy value of starch.[3] In his experiments the starch was added to a basal ration of hay and grain, the balance of carbon and nitrogen on each

[1] ARMSBY, H. P., and FRIES, J. A. INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED. *In* Jour. Agr. Research, v. 11, no. 10, p. 451–472, pl. 41. Literature cited, p. 464. 1917.

[2] ——— ——— NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In* Jour. Agr. Research, v. 3, no. 6, p. 469–470. 1915.

[3] KELLNER, O., and KÖHLER, A. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ DES ERWACHSEHEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER. *In* Landw. Vers, Sta., Bd. 53, 474 p. 1900.

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ration being determined with a respiration apparatus and the heat production computed. A difference calculation, after making certain corrections, shows the net energy of the added starch.

PERIOD AND RATIONS

Each feeding period covered three weeks, of which the first 11 days constituted the preliminary period while during the last 10 the feces and urine were collected quantitatively. A 48-hour determination of the respiratory products and of the heat production was made on the eighteenth and nineteenth days of each period. The dates of the several periods, the rations fed and the average live weight of the animal in each period are shown in Table I.

TABLE I.—*Periods, rations, and average live weights*

Period.	Preliminary period.	Digestion period.	Daily rations.		Live weights of steer.
			Hay.	Starch.	
	1912–13.	1913.	*Kgm.*	*Kgm.*	*Kgm.*
Period 1	Dec. 22–Jan. 1	Jan. 2–Jan. 11	7.50	3.00	388.7
Period 2	Jan. 12–Jan. 22	Jan. 23–Feb. 1	3.00	1.20	366.5
Period 3	Feb. 2–Feb. 12	Feb. 13–Feb. 22	4.25	1.70	387.0
Period 4	Feb. 23–Mar. 5	Mar. 6–Mar. 15	2.00	.80	356.2
Period 5	Mar. 16–Mar. 26	Mar. 27–Apr. 5	9.00	......	403.8
Period 6	Apr. 6–Apr. 16	Apr. 17–Apr. 26	7.00	......	403.2
Period 7	Apr. 27–May 7	May 8–May 17	4.00	......	377.0

COMPOSITION OF FEEDING STUFFS

The alfalfa hay was from a car of baled hay purchased the previous year in Kansas City, Mo., and stated to have been grown in Idaho. The starch was commercial cornstarch

TABLE II.—*Composition and energy content of dry matter of feeding stuffs*

	Alfalfa hay.					Starch, Periods 1-4.
	Period 1.	Periods 2 and 3.	Periods 4 and 5.	Periods 6 and 7.	Average.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ash	9.74	8.83	9.27	9.43	9.26	0.24
Protein	11.34	10.96	11.36	11.51	11.29	.35
Nonprotein	3.27	3.21	3.03	3.12	3.14	....
Crude fiber	30.69	31.86	29.46	29.96	30.47	.13
Nitrogen-free extract	43.22	43.38	45.14	44.21	44.10	99.28
Ether extract	1.84	1.76	1.74	1.77	1.77	....
	100.00	100.00	100.00	100.00	100.00	100.00
Total nitrogen	2.51	2.44	2.46	2.51	2.48	.06
Protein nitrogen	1.82	1.75	1.82	1.84	1.81	....
Carbon	45.00	44.94	44.98	44.74	44.92	43.64
Energy, calories per kgm.	4,335.34	4,389.90	4,332.82	4,334.67	4,348.18	4,104.85

Four samples of the finely cut alfalfa hay and four of the starch were taken as the rations were being weighed out. The hay samples were analyzed separately, while the starch samples were united to form a single composite. The analytical results and the periods covered by each sample are shown in Table II.

DIGESTIBILITY

The digestibility of the total ration was determined in the usual manner. The results are recorded in full in Table 1 of the Appendix and are summarized in Table III. The weighted means are computed from the totals of each ingredient eaten and excreted respectively in all the periods averaged. The digestibility of the starch is computed on the assumption that the hay fed with it had the digestibility shown by the mean of periods 5, 6 and 7. Large negative coefficients for protein and crude fiber result from this computation. The results for the other ingredients are as shown in the table, the periods being, for convenience of reference, grouped by the nature of the ration and arranged in each group in the order of magnitude of the rations.

TABLE III.—*Summary of percentage digestibility*

Feed and period.	Dry matter.	Ash.	Organic matter.	Protein.	Nonprotein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total nitrogen.	Carbon.	Energy.
ALFALFA HAY											
Period 5, 7,893 gm	58.22	41.04	59.98	66.86	87.15	41.24	70.35	15.96	72.57	56.94	56.73
Period 6, 6,128 gm	59.49	40.92	61.42	69.21	89.52	44.07	71.27	8.96	72.64	57.59	57.55
Period 7, 3,502 gm	60.47	42.31	62.36	69.54	90.65	44.71	72.04	22.49	73.55	58.64	58.65
Weighted means	59.11	41.25	60.96	68.23	88.66	42.94	71.00	14.81	72.79	57.50	57.40
ALFAFA HAY AND STARCH											
Period 1, 8,821 gm	68.86	44.54	70.68	60.04	87.64	39.26	83.11	23.57	62.99	67.64	67.30
Period 3, 5,299 gm	67.73	48.86	69.00	56.13	88.86	41.85	81.20	21.18	62.80	66.04	65.98
Period 2, 3,750 gm	70.12	47.42	71.65	61.92	88.57	44.96	83.43	17.81	66.31	68.74	68.57
Period 4, 2,480 gm	70.61	48.63	72.17	63.13	88.70	42.80	84.09	11.15	64.68	68.95	68.48
Weighted means	69.01	46.62	70.61	59.77	88.25	41.49	82.78	20.45	63.71	67.58	67.34
Weighted means, omitting period 3	69.46	45.88	71.17	61.01	88.04	41.35	83.36	20.20	64.07	68.13	67.82
STARCH											
(Computed using mean digestibility of hay)											
Period 1	92.62	....	92.11	....	....	....	96.46	....	....	93.10	92.78
Period 3	88.55	....	86.76	....	....	....	91.96	....	....	87.28	88.14
Period 2	96.48	....	95.03	....	....	....	96.45	....	....	96.45	97.16
Period 4	98.39	....	96.80	....	....	....	98.46	....	....	97.48	96.75
Weighted means	92.98	....	91.83	....	....	....	95.53	....	....	92.74	92.87
Weighted means, omitting period 3	94.55	....	93.61	....	....	....	96.80	....	....	94.66	94.53

The negative coefficients obtained for the protein and crude fiber of the starch by the foregoing method of computation are, of course, sinply an expression of the well-known fact that the addition of starch to a ration

usually results in depressing the digestibility of these ingredients. If it be assumed that the starch was completely digestible—that is, if all the effects just mentioned be assigned to the hay—the digestibility of the latter as compared with that observed in the periods when the hay was fed alone was as shown in Table IV.

TABLE IV.—*Influence of starch on digestibility of hay*

	Dry matter.	Ash.	Organic matter.	Protein.	Nonprotein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total nitrogen.	Carbon.	Energy.
Computed digestibility, assuming 100 per cent for starch:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Period 1	56.08	43.96	57.38	59.54	87.64	39.15	67.80	23.57	62.64	54.75	54.59
Period 3	50.83	48.28	54.96	55.55	88.86	41.76	63.37	21.18	62.43	52.38	52.82
Period 2	57.64	46.81	58.69	61.42	88.57	44.77	67.60	17.81	66.01	56.06	56.30
Period 4	58.44	48.07	59.50	62.67	88.70	42.70	69.60	11.15	64.35	56.48	56.12
Weighted means	56.21	46.03	57.25	59.25	88.25	41.39	66.86	20.45	63.40	54.54	54.62
Weighted means, omitting period 3	56.86	45.29	58.06	60.51	88.04	41.25	68.05	20.20	63.73	55.36	55.27
Observed digestibility	59.11	41.25	60.96	68.23	88.66	42.94	71.00	14.81	72.79	57.50	57.40
Difference	−2.25	+4.04	−2.90	−7.72	−0.62	−1.67	−2.95	+5.39	−9.06	−2.14	−2.13

In some respects a more rational method of expressing this depression in digestibility is in terms of the actual amounts instead of the percentages of the various ingredients. Table V shows the number of grams by which the several nutrients actually digested from the mixed ration of periods 1 to 4 differ from what would be expected on the same assumption as in Table IV.

TABLE V.—*Depression of digestibility by starch*

Period No.	Protein.	Nonprotein.	Crude fiber.	Total nitrogen.
	Gm.	*Gm.*	*Gm.*	*Gm.*
1	61.7	2.1	68.6	16.0
3	52.1	−.2	14.1	9.5
2	19.7	.1	−16.3	4.4
4	11.1	.0	1.2	3.6

INFLUENCE OF QUANTITY OF FEED ON DIGESTIBILITY

The figures of Table III show a distinct influence of the quantity of feed upon the percentage digestibility, as has been the case in most previous experiments.[1] The digestibility increases as the amount consumed is decreased, although the differences are relatively small. To this rule period 3 constitutes a distinct exception. As will appear, the results of

[1] ARMSBY, H. P. THE NUTRITION OF FARM ANIMALS. p. 613–618. New York, 1917.
——— and FRIES, J. A. ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE. *In* Jour. Agr. Research, v. 10, no. 12, p. 605. 1917.
——— ———. INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED. *In* Jour. Agr. Research, v. 11, no. 10, p. 453. 1917.
——— ——— and BRAMAN, W. W. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In* Jour. Agr. Research, v. 7, no. 9, p. 381. 1916.

this period appear somewhat exceptional in other respects also, and the mean digestibility, excluding period 3, is therefore included in the table.

URINARY EXCRETION

From the results for the urinary excretion contained in Table 2 of the Appendix the following averages are derived. Table VI shows both the energy of the urine as actually determined and also with a correction of 7.45 Calories per gram for the gain or loss of nitrogen by the body.

TABLE VI.—*Average daily excretion in urine*

Feed and period.	Nitrogen.	Carbon.	Energy.		Ratio of nitrogen to carbon.	Observed energy.	
			Observed.	Corrected to nitrogen equilibrium.		Per gram of nitrogen.	Per gram of carbon.
ALFALFA HAY.	*Gm.*	*Gm.*	*Cal.*	*Cal.*		*Cal.*	*Cal.*
Period 5	129.7	196.4	1,916.1	1,992.1	1:1.51	14.77	9.76
Period 6	100.9	151.5	1,489.5	1,560.3	1:1.50	14.76	9.83
Period 7	70.6	107.7	997.5	943.9	1:1.53	14.13	9.26
ALFALFA HAY AND STARCH							
Period 1	66.8	140.5	1,229.0	1,467.4	1:2.10	18.40	8.75
Period 3	49.7	100.5	902.6	955.5	1:2.02	18.16	8.98
Period 2	43.1	78.3	733.3	725.1	1:1.82	17.01	9.37
Period 4	35.1	58.8	564.9	505.3	1:1.68	16.09	9.61

GASEOUS EXCRETION

The excretion of water vapor, carbon dioxid, and methane for each day is recorded in Table 4 of the Appendix. The average results for each period were as follows:

TABLE VII.—*Average daily gaseous excretion*

Feed and period.	Water.	Carbon dioxid.	In combustible gases.		Methane computed from carbon.	Ratio of hydrogen to carbon.
			Hydrogen.	Carbon.		
ALFALFA HAY.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
Period 5	6,995.3	5,505.0	42.4	129.6	173.2	3.057
Period 6	5,458.7	4,568.6	33.5	99.3	132.7	2.970
Period 7	3,460.1	3,252.5	26.1	59.3	79.2	2.267
ALFALFA HAY AND STARCH.						
Period 1	10,028.1	7,045.5	54.9	168.5	225.1	3.069
Period 3	5,252.6	4,724.9	37.7	116.7	155.9	3.092
Period 2	4,384.3	3,909.5	27.1	83.8	112.0	3.092
Period 4	3,168.8	3,133.7	19.8	62.4	83.3	3.145

GAINS BY BODY

From the data of the Appendix the gains of protein, fat, and water by the animal can be computed in the usual way with the results there recorded in Table 6. In this computation the amount of water produced by the oxidation of organic hydrogen has been disregarded. The results are used only as a correction in the manner described on page 277, and it may be shown that a disregard of the organic hydrogen introduces no material error. Table VIII contains a summary of the gains of protein and fat by periods.

TABLE VIII.—*Average daily gains of protein and fat*

Feed and period.	Protein.	Fat.
ALFALFA HAY.	*Gm.*	*Gm.*
Period 5	61.2	205.3
Period 6	57.0	60.9
Period 7	−43.2	−154.0
ALFALFA HAY AND STARCH.		
Period 1	192.0	422.9
Period 3	42.6	34.1
Period 2	− 6.6	−106.2
Period 4	−48.0	−252.6

METHANE FERMENTATION

The extent of the methane fermentation per kilogram of dry matter of the feed and per 100 gm. of digested carbohydrates is shown in Table IX. In the hay the carbohydrates are the sum of the digested crude fiber and nitrogen-free extract, while in the case of starch the comparison is made with the digested nitrogen-free extract. The minute amount of crude fiber contained in the starch, as already noted, showed an apparent negative digestibility.

The extent to which the carbohydrates of the hay were subject to the methane fermentation was substantially the same as the average of 17 previous determinations on alfalfa[1]—viz, 4.9 gm. of CH_4 per 100 gm. of carbohydrates as compared with an average of 4.8. With the mixed ration of hay and starch the fermentation showed a distinct increase as the amount of feed was diminished. When, as in the latter part of the table, this increase is computed upon the starch alone, assuming average figures for the hay, it becomes, of course, relatively more marked and considerably exceeds Kellner's average of 3.07.[2] The relative extent of the fermentation was apparently abnormally great in period 3 which, as already noted, also gave apparently exceptional results as regards digestibility. The means, omitting period 3, have therefore been included in the table.

[1] ARMSBY, H. P., and FRIES, J. A. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In* Jour. Agr. Research, v. 3, no. 6, p. 450. 1915.

[2] KELLNER, O., and KÖHLER, A. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ DES ERWACHSENEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER. *In* Landw. Vers. Stat., Bd. 53, p. 423, 1900.

TABLE IX.—*Methane production*

Feed and period.	Dry matter eaten.	Methane. Total.	Methane. Per kilogram of dry matter.	Methane. Per 100 grams of digested carbohydrates.
ALFALFA HAY.	*Gm.*	*Gm.*	*Gm.*	*Gm.*
Period 5	7,893.0	173.19	21.94	5.0
Period 6	6,127.8	132.74	21.66	4.8
Period 7	3,501.6	79.19	22.61	5.0
Totals and means	17,522.4	385.12	21.98	4.9
ALFALFA HAY AND STARCH.				
Period 1	8,821.0	225.14	25.52	4.4
Period 3	5,298.8	155.93	29.42	5.1
Period 2	3,750.4	112.00	29.86	5.0
Period 4	2,480.0	83.34	33.60	5.6
Totals and means	20,350.2	576.41	28.32	4.8
Totals and means, omitting period 3	15,051.4	420.48	27.94	4.7
STARCH, COMPUTED, WITH MEAN FOR HAY.				
Period 1, total	8,821.0	225.14		
Period 1, hay	6,254.7	137.48		
Period 1, starch	2,566.3	87.66	34.16	3.6
Period 3, total	5,298.8	155.93		
Period 3, hay	3,747.7	82.37		
Period 3, starch	1,551.1	73.56	47.42	5.2
Period 2, total	3,750.4	112.00		
Period 2, hay	2,645.4	58.15		
Period 2, starch	1,105.0	53.85	48.73	5.1
Period 4, total	2,480.0	83.34		
Period 4, hay	1,754.0	38.55		
Period 4, starch	726.0	44.79	61.70	6.3
Totals and means	5,948.4	259.86	43.69	4.6
Totals and means, omitting period 3	4,397.3	186.30	42.37	4.4

METABOLIZABLE ENERGY

By metabolizable energy is understood the total chemical energy of the feed, as measured by its heat of combustion, minus the chemical energy lost in the feces, urine, and combustible gases. In other words, it is the amount of energy capable of conversion into other forms in the body. Correcting the observed energy of the urine to a state of nitrogen equilibrium[1] the following results (Table X) may be computed as in the case of digestibility. Averages have also been computed omitting the results of period 3.

[1] By adding 7.45 Calories for each gram of nitrogen retained by the animal or subtracting the same amount for each gram of body nitrogen lost, the correction being regarded as representing energy of excretory material temporarily retained in the body.

TABLE X.—*Losses of chemical energy; metabolizable energy*

Feed and period.	Energy per kilogram of dry matter.					Metabolizable energy per kilogram digestible organic matter.	Percentage losses.			Percentage metabolizable.
	Total.	Losses.			Metabolizable.		In feces.	In urine.	In methane.	
		In feces.	In urine.[a]	In methane.						
ALFALFA HAY.	Cal.	Cal.	Cal.	Cal.	Cal.	Cal.				
Period 5	4,333	1,875	252	293	1,913	3,516	43.27	5.82	6.76	44.15
Period 6	4,335	1,840	255	289	1,951	3,507	42.45	5.87	6.67	45.01
Period 7	4,335	1,792	270	302	1,971	3,490	41.35	6.22	6.96	45.47
Weighted averages.	4,334	1,846	257	293	1,938	3,507	42.60	5.92	6.77	44.71
ALFALFA HAY AND STARCH.										
Period 1	4,267	1,395	166	341	2,365	3,596	32.70	3.90	7.98	55.42
Period 3	4,306	1,465	180	393	2,268	3,509	34.02	4.20	9.12	52.66
Period 2	4,306	1,353	193	398	2,362	3,516	31.43	4.49	9.26	54.82
Period 4	4,266	1,345	204	448	2,269	3,368	31.51	4.78	10.51	53.20
Weighted averages.	4,284	1,400	180	378	2,326	3,530	32.68	4.20	8.82	54.30
Weighted averages for periods 1, 2, and 4	4,276	1,376	179	373	2,348	3,538	32.18	4.19	8.72	54.91
COMPUTED FOR STARCH.										
Period 1	4,105	296	-53	456	3,406	3,707	7.22	-1.30	11.10	82.98
Period 3	4,105	487	-12	623	3,007	3,474	11.86	-0.29	15.19	73.24
Period 2	4,105	116	34	541	3,314	3,495	2.84	0.83	15.62	80.71
Period 4	4,105	134	76	823	3,072	3,182	3.25	1.86	20.05	74.84
Weighted averages.	4,105	293	-11	579	3,244	3,541	7.14	-0.24	14.10	79.03
Weighted averages for periods 1, 2, and 4	4,105	224	-10	563	3,328	3,563	5.46	-0.24	13.71	81.07
Kellner's average	4,152	731	-27	382	3,066	3,603	17.61	-0.66	9.21	73.84

[a] Corrected to N equilibrium.

It has already been noted that with the exception of period 3 the digestibility increased as the total amount of the ration was decreased. The converse of this is shown in Table X, of course, in the decreased losses in the feces. On the other hand, the losses in the urine and methane show a distinct increase on the lower rations. As in previous experiments, the greater digestibility of the smaller rations was apparently due largely to the greater extent of the methane fermentation accompanied by the excretion of more katabolic products of some sort in the urine. As a consequence, the metabolizable energy per kilogram of digested dry matter

or of digested organic matter was somewhat less on the lighter rations despite their higher digestibility. The difference would be still more marked if account were taken of the fact that on the lighter rations a larger proportion of the metabolizable energy is accounted for by the heat of fermentation of the carbohydrates.

The metabolizable energy per kilogram of digested organic matter agrees closely with the results obtained by us [1] in earlier experiments on roughage and by Kellner [2] in his experiments on starch.

HEAT EMISSION AND PRODUCTION

The results of the measurements of heat emission are contained in Table 5 of the Appendix. The heat emission, however, does not usually correspond with the heat production.

First, any matter gained by the body is raised from the temperature of the calorimeter to the temperature of the body and a corresponding amount of the heat produced is stored up as heat in this added material.

Second, a rise in body temperature while the animal is in the calorimeter likewise absorbs a certain amount of the heat actually produced. Both these amounts must therefore be added to the heat emission to get the real heat production. Of course this correction may be negative—that is, a fall of body temperature or a loss of body weight gives a negative correction—so that in such a case the heat production is less than the heat emission. The corrections due to these two causes are shown in the Appendix, Tables 6 and 7, while Table 8 shows the heat emission, the corrections, the heat production as thus computed and also the heat production as computed in the usual way from the balance of nitrogen and carbon—that is, by indirect calorimetry.

CORRECTION FOR STANDING AND LYING

Standing as compared with lying exerts such a marked influence upon the metabolism of cattle that it is necessary to make a correction for this factor in order to render the different periods of an experiment comparable. The heat production has therefore been computed to 12 hours each standing and lying in the manner described in a previous paper.[3] On using the same corrections as before for body gain and body temperature the results are as shown in Table XI.

[1] ARMSBY, H. P., and FRIES, J. A. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In* Jour. Agr. Research, v. 3, no. 6, p. 451. 1915.

——— ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE. *In* Jour. Agr. Research, v. 10, no. 12, p. 605. 1917.

——— and BRAMANN, W. W. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In* Jour. Agr. Research, v. 7, no. 9, p. 382.

[2] ARMSBY, H. P. THE NUTRITION OF FARM ANIMALS. p. 301. New York, 1917.

——— and FRIES, J. A. OP. CIT., 1915, p. 452.

[3] ARMSBY, H. P., and FRIES, J. A. OP. CIT., 1915, p. 454.

TABLE XI.—*Daily heat production computed to 12 hours' standing and lying.*

Period and ration.	First day.	Second day.	Mean.
ALFALFA HAY.	*Calories.*	*Calories.*	*Calories.*
Period 5	13, 309	13, 187	13, 248
Period 6	10, 940	11, 512	11, 226
Period 7	8, 981	8, 747	8, 864
ALFALFA HAY AND STARCH.			
Period 1	16, 394	15, 635	16, 015
Period 3	11, 283	11, 439	11, 361
Period 2	10, 150	9, 689	9, 920
Period 4	8, 483	8, 325	8, 404

ENERGY EXPENDITURE CONSEQUENT UPON FEED CONSUMPTION

The heat production in this experiment shows the same marked dependence upon the amount of feed consumed which has been noted in all previous investigations. By a difference computation, the heat increment caused by a unit of feed consumed may be computed. For example, a comparison of periods 5 and 7 gives the following results:

TABLE XII.—*Example of computation of heat increment due to feed*

Period.	Dry matter eaten.	Heat production.
	Gm.	*Calories.*
Period 5	7, 893	13, 248
Period 7	3, 502	8, 864
Difference	4, 391	4, 384
Difference per kilogram of dry matter		999

TABLE XIII.—*Heat increment per kilogram of dry matter*

Feed and period.	Heat production per kilo.	Feed and period.	Heat production per kilo.
ALFALFA HAY.	*Cal.*	ALFALFA HAY AND STARCH—con.	*Cal.*
Periods 5–6	1, 146	Periods 1–4	1, 200
Periods 6–7	899		
Periods 5–7	999	STARCH.	
ALFALFA HAY AND STARCH.		Periods 1–3	2, 118
		Periods 3–2	762
Periods 1–3	1, 321	Periods 2–4	1, 649
Periods 3–2	931	Periods 1–2	1, 704
Periods 2–4	1, 192	Periods 1–4	1, 692
Periods 1–2	1, 202		

In the same manner the heat increment per kilogram of the mixed ration of hay and starch may be computed, while by a comparison of these results with those on hay the energy expenditure per kilogram of

starch may be calculated. Three comparisons are obviously possible on the hay and five on the mixed ration. The results are contained in Table XIII.

It may be presumed that, other things being equal, the results obtained by comparing the extreme periods—namely, periods 5 and 7 for hay and periods 1 and 4 for the mixed ration—will be the most accurate. In the case of the hay the intermediate comparisons show differences similar to those already reported.[a] In the case of the mixed ration and of the starch the results show a marked degree of uniformity with the exception of those involving period 3. As already noted, the results of this period as regards digestibility, methane production, and metabolizable energy appear somewhat abnormal as compared with those of periods 1, 2, and 4, the losses in feces and methane being relatively large and the percentage of the gross energy which was metabolizable being correspondingly lower. This might be expected to result in a lower heat production. If such were the fact, it would tend to explain the marked divergence of those heat increments in Table XIII which involve the use of period 3. We are inclined therefore to accept the results of the extreme periods—viz,

Hay	999 Calories per kilogram
Hay and starch	1,200 Calories per kilogram
Starch	1,692 Calories per kilogram

as representing most accurately the heat increment caused by the consumption of these materials.

NET ENERGY VALUES

Subtracting from the gross energy the losses of chemical energy and the heat increment due to feed consumption gives the net energy value as follows (Table XIV):

TABLE XIV.—*Net energy values per kilogram of dry matter*

Feed and period.	Gross energy.	Losses of chemical energy.	Metabolizable energy.	Heat increment.	Net energy values.	Net metabolizable.
ALFALFA HAY.	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Per ct.*
Average	4,334	2,396	1,938	[b] 999	939	48.45
ALFALFA HAY AND STARCH.						
Average of all	4,284	1,958	2,326	[c] 1,200	1,126	48.41
Average of periods 1, 2, and 4	4,276	1,928	2,348	[c] 1,200	1,148	48.89
STARCH.						
Average of all	4,105	861	3,244	[c] 1,692	1,552	47.84
Average of periods 1, 2, and 4	4,105	777	3,328	[c] 1,692	1,636	49.16
Kellner's average	4,152	1,101	3,051	1,248	1,803	58.80

[a] ARMSBY, H. P., and FRIES, J. A. OP. CIT., 1915, p. 473-475.
[b] From results of periods 5 and 7.
[c] From results of periods 1 and 4.

COMPARISON WITH KELLNER'S RESULTS ON STARCH

As noted at the beginning of this article, Kellner has reported a number of determinations of the net energy of starch. His results, expressed in terms of energy and computed in a somewhat different manner than that used by Kellner himself,[1] are included in Table XIV. Two marked differences appear. Kellner's metabolizable energy is lower than that found in our experiment, while his heat increment is also less, the net result being a higher net energy value. Kellner's rations, however, differ quite materially from ours. As regards quantity (total organic matter) our mixed ration was considerably above Kellner's in period 1 and much below it in periods 2 and 4. As regards make-up it contained a much larger proportion of hay and no concentrate except starch. The percentage of starch in the total ration was 31.2 as against 19.2 in Kellner's, but the percentage of organic matter supplied by the hay was 69.8 as compared with 40.9 in Kellner's experiments. As regards nutritive ratio our ration was somewhat narrower than three of Kellner's rations and somewhat wider than the other two.

The difference in the metabolizable energy is due chiefly to a much larger loss in the feces in Kellner's experiments, as Table X shows. If this be eliminated, by computing the losses in urine and methane upon the digested energy the following comparisons are obtained:

TABLE XV.—*Distribution of digested energy of starch*

	In urine.	In methane.	Metabolizable.
	Per cent.	*Per cent.*	*Per cent.*
Mean of periods 1, 2, and 4	−0.26	14.50	85.76
Kellner's mean	− .79	11.17	89.62

The higher digestibility of the starch in our experiment was accompanied (caused?) by a greater production of methane, so that a less proportion of the digested energy was metabolizable. When thus computed on the digested energy, our results in period 1 agree substantially with Kellner's, while periods 2 and 4 show a considerably greater relative loss of energy in the methane. Period 3, as already noted, appears exceptional. No obvious explanation presents itself for the high heat increment found in our experiment. The more extensive fermentation of the starch may perhaps account for a portion, but by no means all of it.

[1] ARMSBY, H. P. OP. CIT., 1917, p. 455–459, 474.

SUMMARY

In seven respiration calorimeter experiments on a steer the digestibility and metabolizable energy of different amounts of alfalfa hay and of a mixture of alfalfa hay and commercial starch the gaseous excretion and the heat production were determined.

By a comparison of periods in which different amounts of the same ration were fed, the heat increments consequent on feed consumption and the net energy values of the rations were computed.

The digestibility of the rations, the losses in the urine, and the extent of the methane fermentation showed a distinct increase as the total amount of the ration was reduced.

The greater loss of energy in the urine and methane on the lighter rations more than compensated for the smaller losses in the feces, so that the proportion of the total energy metabolizable was somewhat less than on the heavier rations.

The metabolizable energy of the starch was 10 per cent greater than the average computed from five experiments by Kellner, the difference being due chiefly to smaller losses in the feces. Starch caused the usual depresion in digestibility.

The average heat increment caused by the consumption of alfalfa hay was 999 Calories per kilogram of dry matter as compared with 981 Calories found for the same hay in the previous year and with an average of 1,169 Calories in six previous experiments on three different samples.

The average heat increment for the starch was 1,692 Calories per kilogram of dry matter as compared with 1,248 Calories computed from Kellner's experiments.

The net energy values of the starch was about 9 per cent lower than that computed from Kellner's experiments, only 49 per cent, as compared with 59 per cent of the metabolizable energy being utilized by the animal.

APPENDIX

The principal numerical data obtained in the experuments are recorded in the following tables. The computations involved have been carried out beyond the probable limit of accuracy of the experimental methods in order to guard against a possible accumulation of arithmetical errors.

TABLE 1.—*Digestibility of rations*

Feed and period.	Dry matter.	Ash.	Organic matter.	Protein.	Non-protein.	Crude fiber.	N-free extract	Ether extract.	Total nitrogen.	Carbon	Energy.
ALFALFA HAY.											
Period 5:	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Calories.*
Total fed	7,893.0	732.0	7,161.0	896.9	238.9	2,325.5	3,562.5	137.2	194.3	3,550.3	34,198.95
Feces	3,297.6	431.6	2,866.0	297.2	30.7	1,366.5	1,056.3	115.3	53.3	1,528.7	14,796.30
Amount digested	4,595.4	300.4	4,295.0	599.7	208.2	959.0	2,506.2	21.9	141.0	2,021.6	19,402.65
Percentage digestibility	58.22	41.04	59.98	66.86	87.15	41.24	70.35	15.96	72.57	56.94	56.73
Period 6:											
Total fed	6,127.8	577.9	5,549.9	705.5	190.9	1,836.1	2,709.1	108.2	153.5	2,741.3	26,561.99
Feces	2,482.4	341.4	2,141.0	217.2	20.2	1,026.9	778.3	98.5	42.0	1,162.7	11,276.20
Amount digested	3,645.4	236.5	3,408.9	488.3	170.7	809.2	1,930.8	9.7	111.5	7,578.6	15,285.79
Percentage digestibility	59.49	40.92	61.42	69.21	89.52	44.07	71.27	8.96	72.64	57.59	57.55
Period 7:											
Total fed	3,501.6	330.2	3,171.4	403.1	109.1	1,049.2	1,548.1	61.8	87.7	1,566.4	15,178.28
Feces	1,384.2	190.5	1,193.7	122.8	10.2	580.1	432.8	47.9	23.2	647.9	6,276.31
Amount digested	2,117.4	139.7	1,977.7	280.3	98.9	469.1	1,115.3	13.9	64.5	918.5	8,901.97
Percentage digestibility	60.47	42.31	62.36	69.54	90.65	44.71	72.04	22.49	73.55	58.65	58.65
ALFALFA HAY AND STARCH.											
Period 1:											
Alfalfa hay	6,629.3	646.0	5,983.3	752.0	216.8	2,034.4	2,858.4	121.8	166.5	2,983.2	28,740.3
Starch	2,729.1	6.7	2,722.4	9.5	......	3.4	2,709.5	......	1.6	1,191.0	11,202.5
Total fed	9,358.4	652.7	8,705.7	761.5	216.8	2,037.7	5,567.9	121.8	168.1	4,174.2	39,942.8
Refused	537.4	40.4	497.0	42.3	12.9	223.1	211.9	6.8	9.5	241.6	2,303.7
Amount eaten	8,821.0	612.3	8,208.7	719.2	203.9	1,814.6	5,356.0	115.0	158.6	3,932.6	37,639.1
Feces	2,746.8	339.6	2,407.2	287.4	25.2	1,102.2	904.4	87.9	58.7	1,272.7	12,307.6
Amount digested	6,074.2	272.7	5,801.5	431.8	178.7	712.4	4,451.6	27.1	99.9	2,659.9	25,331.5
Percentage digestibility	68.86	44.54	70.68	60.04	87.64	39.26	83.11	23.57	62.99	67.64	67.30
Period 3:											
Alfalfa hay	3,747.7	330.8	3,416.9	410.6	120.3	1,194.1	1,625.8	66.1	91.3	1,684.3	16,452.03
Starch	1,551.1	3.8	1,547.3	5.4	......	1.9	1,540.0	......	.9	676.9	6,367.03
Total eaten	5,298.8	334.6	4,964.2	416.0	120.3	1,196.0	3,165.8	66.1	92.2	2,361.2	22,819.06
Feces	1,710.0	171.1	1,538.9	182.5	13.4	695.5	595.3	52.1	34.3	801.9	7,763.81
Amount digested	3,588.8	163.5	3,425.3	233.5	106.9	500.5	2,570.5	14.0	57.9	1,559.3	15,055.25
Percentage digestibility	67.73	48.86	69.00	56.13	88.86	41.85	81.20	21.18	62.80	66.04	65.98
Perod 2:											
Alfalfa hay	2,645.4	233.5	2,411.9	289.8	84.9	842.9	1,148.3	46.6	64.44	1,188.9	11,613.04
Starch	1,105.0	2.7	1,102.3	3.8	......	1.4	1,097.1	......	.6	482.2	4,535.86
Total eaten	3,750.4	236.2	3,514.2	293.6	84.9	844.3	2,245.4	46.6	65.0	1,671.1	16,148.90
Feces	1,[illegible]0.6	124.2	996.4	111.8	9.7	464.7	372.0	38.3	21.9	522.4	5,075.81
Amount digested	2,629.8	112.0	2,517.8	181.8	75.2	379.6	1,873.4	8.3	43.1	1,148.7	11,073.09
Percentage digestibility	70.12	47.42	71.65	61.92	88.57	44.96	83.43	17.81	66.31	68.74	68.57
Period 4:											
Alfalfa hay	1,754.0	162.7	1,591.3	199.3	53.1	516.8	791.7	30.5	43.2	788.9	7,599.76
Starch	726.0	1.8	724.2	2.5	......	.9	720.8	......	.4	316.8	2,980.12
Total eaten	2,480.0	164.5	2,315.5	201.8	53.1	517.7	1,512.5	30.5	43.6	1,105.7	10,579.88
Feces	728.9	84.5	644.4	74.4	6.0	296.1	240.7	27.1	15.4	343.3	3,334.40
Amount digested	1,751.1	80.0	1,671.1	127.4	47.1	221.6	1,271.8	3.4	28.2	762.4	7,245.48
Percentage digestibility	70.61	48.63	72.17	63.13	88.70	42.80	84.09	11.15	64.68	68.9	68.48

TABLE 2.—*Urinary excretion*

Feed and period.	Weight.	Average specific gravity.	Total solids.		Total nitrogen.		Total carbon.		Energy.	
									Per gram.	Total.
ALFALFA HAY.	*Gms.*		*Per cent.*	*Gms.*	*Per cent.*	*Gms.*	*Per cent.*	*Gms.*	*Calories.*	*Calories.*
Period 5:										
Collected	95,884	1.041	8.26	7,920.0	1.347	1,291.6	2.040	1,956.0	.1990	19,080.9
Spilled	1,245			33.1		5.4		8.2		79.8
Total, 10 days	97,129			7,953.1		1,297.0		1,964.2		19,160.7
Average	9,712.9			795.3		129.7		196.4		1,916.1
Period 6:										
Collected	90,763	1.035	6.08	5,518.4	1.097	995.7	1.647	1,494.9	.1619	14,694.5
Spilled	1,451			75.4		13.6		20.4		200.7
Total, 10 days	92,214			5,593.8		1,009.3		1,515.3		14,895.2
Average	9,221.4			559.4		100.9		151.5		1,489.5
Period 7:										
Collected	66,059	1.068	6.01	3,970.1	1.068	705.5	1.631	1,077.4	.1510	9,974.9
Average	6,605.9			397.0		70.6		107.7		997.5
ALFALFA HAY AND STARCH.										
Period 1:										
Collected	68,544	1.044	8.768	6,009.9	.948	649.8	1.995	1,367.5	.1745	11,960.9
Spilled	2,943			157.2		17.9		37.7		329.5
Total, 10 days	71,487			6,167.1		667.7		1,405.2		12,290.4
Average	7,148.7			616.7		66.7		140.5		1,229.0
Period 3:										
Collected	71,192	1.0302	4.45	3,168.0	.696	495.5	1.406	1,001.0	.1263	8,991.5
Spilled	805			12.1	.238	1.9		3.8		34.5
Total, 10 days	71,997			3,180.1		497.4		1,004.8		9,026.0
Average	7,199.7			318.0		49.7		100.5		902.6
Period 2:										
Collected, 10 days	60,057	1.030	5.586	3,354.8	.718	431.2	1.304	783.1	.1221	7,333.0
Average	6,005.7					43.1		78.3		733.3
Period 4:										
Collected, 10 days	39,042	1.0308	5.533	2,160.2	.899	351.0	1.506	588.0	.1447	5,649.4
Average	3,904.2			216.0		35.1		58.8		564.9

TABLE 3.—*Average daily production of epidermal tissue*

Factor.	In growth of hair.	In brushings.	Total.
Dry matter ... gm.	2.20	9.19	11.39
Nitrogen ... gm.	0.33	.73	1.06
Carbon ... gm.	1.09	3.96	5.05
Energy ... Cal.	11.99	43.13	55.12

TABLE 4.—*Gaseous excretion*

Feed and period.	Water.	Carbon dioxid.	In combustible gases.		Methane computed from carbon.	Ratio, hydrogen to carbon.
			Hydrogen.	Carbon.		
ALFALFA HAY.						
Period 5:	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
First day	7,101.04	5,570.91	43.35	132.19	176.65	3.049
Second day	6,889.56	5,439.04	41.44	127.01	169.72	3.065
Average	6,995.30	5,504.98	42.40	129.60	173.19	3.057
Period 6:						
First day	5,570.20	4,597.76	34.00	102.50	136.96	3.015
Second day	5,341.17	4,539.40	32.89	96.17	128.51	2.924
Average	5,458.69	4,568.58	33.45	99.34	132.74	2.970
Period 7:						
First day	3,525.93	3,266.36	29.39	60.30	80.57	2.052
Second day	3,394.18	3,238.68	22.89	58.22	77.80	2.543
Average	3,460.06	3,252.52	26.14	59.26	79.19	2.267
ALFALFA HAY AND STARCH.						
Period 1:						
First day	10,423.97	7,068.02	56.18	172.75	230.85	3.075
Second day	9,632.29	7,022.94	53.61	164.20	219.43	3.063
Average	10,028.13	7,045.48	54.90	168.48	225.14	3.069
Period 3:						
First day	5,257.87	4,732.27	37.28	115.62	154.50	3.101
Second day	5,247.31	4,717.45	38.19	117.76	157.36	3.084
Average	5,252.59	4,724.86	37.74	116.69	155.93	3.092
Period 2:						
First day	4,559.94	3,929.83	26.86	82.98	110.88	3.089
Second day	4,208.61	3,889.07	27.36	84.65	113.11	3.094
Average	4,384.28	3,903.45	27.11	83.82	112.00	3.092
Period 4:						
First day	3,175.56	3,158.00	20.03	63.16	84.39	3.153
Second day	3,161.98	3,109.36	19.62	61.57	82.28	3.138
Average	3,168.77	3,133.68	19.83	62.37	83.34	3.145

TABLE 5.—*Heat emission*

Feed and period.	By radiation and conduction.	As latent heat of water vapor.	Total.
ALFALFA HAY.			
Period 5:	*Calories.*	*Calories.*	*Calories.*
First day	8,812.59	4,100.60	12,913.18
Second day	8,651.67	4,039.94	12,691.61
Average	8,732.13	4,070.32	12,802.45
Period 6:			
First day	7,742.57	3,273.23	11,015.80
Second day	7,661.46	3,152.17	10,813.63
Average	7,702.02	3,212.70	10,914.72
Period 7:			
First day	6,120.28	2,082.40	8,202.68
Second day	6,271.53	1,996.61	8,268.14
Average	6,195.91	2,039.51	8,235.4

TABLE 5—*Heat emission*—Continued

Feed and period.	By radiation and conduction.	As latent heat of water vapor.	Total.
ALFALFA HAY AND STARCH.			
Period 1:	*Calories.*	*Calories.*	*Calories.*
First day	10,731.85	4,860.76	15,592.61
Second day	10,619.21	4,887.53	15,506.74
Average	10,675.53	4,874.15	15,549.67
Period 3:			
First day	7,744.58	3,086.37	10,830.95
Second day	7,770.84	3,071.71	10,842.55
Average	7,757.71	3,079.04	10,836.75
Period 2:			
First day	7,075.60	2,583.70	9,659.30
Second day	6,986.47	2,457.77	9,444.24
Average	7,031.04	2,520.73	9,551.77
Period 4:			
First day	6,108.95	1,880.96	7,989.91
Second day	6,102.51	1,862.38	7,964.89
Average	6,105.73	1,871.67	7,977.4

TABLE 6.—*Corrections of heat emission for gains by body*[a]

Feed and period.	Gain— Protein.[b]	Fat.	Water.	Mean body temperature.	Calorimeter temperature.	Correction.
ALFALFA HAY.						
Period 5:	*Gm.*	*Gm.*	*Gm.*	°*C.*	°*C.*	*Cal.*
First day	+ 61.2	+178.4	−8,558			−176
Second day	+ 61.2	+232.3	+2,513			+ 56
Average	+ 61.2	+205.3	−3,022	38.58	17.66	− 60
Period 6:						
First day	+ 57.0	+ 46.0	−9,393			−197
Second day	+ 57.0	+ 75.8	+1,242			+ 28
Average	+ 57.0	+ 60.9	−4,076	38.70	17.67	− 85
Period 7:						
First day	− 43.2	−160.2	− 604			− 15
Second day	− 43.2	−147.7	− 52			− 3
Average	− 43.2	−154.0	− 328	38.00	17.71	− 9
ALFALFA HAY AND STARCH.						
Period 1:						
First day	+192.0	+409.2	−7,403			−148
Second day	+192.0	+436.5	+5,938			+131
Average	+192.0	+422.9	− 733	38.67	17.76	− 8
Period 3:						
First day	+ 42.6	+ 32.9	−3,634			− 75
Second day	+ 42.6	+ 35.3	+1,117			+ 25
Average	+ 42.6	+ 34.1	−1,259	38.50	17.69	− 25
Period 2:						
First day	− 6.6	−112.3	−1,480			− 32
Second day	− 6.6	−100.0	− 369			− 9
Average	− 6.6	−106.2	− 924	38.28	17.72	− 21
Period 4:						
First day	− 48.0	−262.3	+ 102			− 2
Second day	− 48.0	−242.8	−1,099			− 26
Average	− 48.0	−252.6	− 499	38.14	17.72	− 14

[a] Estimated specific heats; protein 0.30, fat 0.66.

[b] Average of entire digestion period.

TABLE 7.—*Corrections of heat emission for changes of body temperature in 48 hours*

Feed and period.	Live weight when leaving calorimeter.	Body temperature.[a] Entering.	Leaving.	Difference.	Corrections for body temperature.[b]
ALFALFA HAY.	*Kgm.*	*°C.*	*°C.*	*°C.*	*Cal.*
Period 5	423.2	38.33	38.83	+0.50	+169
Period 6	412.2	38.67	38.72	+0.05	+ 16
Period 7	383.0	37.44	38.56	+1.12	+343
ALFALFA HAY AND STARCH.					
Period 1	409.8	38.67	38.67	0.00	0
Period 3	374.4	38.33	38.67	+0.34	+108
Period 2	398.0	38.22	38.33	+0.11	+ 33
Period 4	364.7	37.94	38.33	+0.39	+114

[a] Taken in Fahrenheit degrees and reduced. [b] Specific heat of body, 0.8.

TABLE 8.—*Daily heat production*

Feed and period.	Heat emission.	Correction for body temperature[a] (Table 7).	Correction for body gain per day (Table 6).	Observed heat production.	Computed heat production.	Computed ÷ observed.
ALFALFA HAY.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Per cent.*
Period 5:						
First day	12,913.3	+ 85	−176	12,822.3	13,030.7	101.6
Second day	12,691.6	+ 85	+ 56	12,832.6	12,611.1	98.3
Average	12,802.5	+ 85	− 60	12,827.5	12,820.9	99.9
Period 6:						
First day	11,015.8	+ 8	−197	10,826.8	11,144.1	102.9
Second day	10,813.6	+ 8	+ 28	10,849.6	10,981.4	101.2
Average	10,914.7	+ 8	− 85	10,837.7	11,062.8	102.0
Period 7:						
First day	8,202.7	+172	− 15	8,359.7	8,542.4	102.2
Second day	8,268.1	+172	− 3	8,437.1	8,460.6	100.3
Average	8,235.4	+172	− 9	8,398.4	8,501.5	101.2
ALFALFA HAY AND STARCH.						
Period 1:						
First day	15,592.6	0	−148	15,444.6	15,985.1	103.5
Second day	15,506.7	0	+131	15,637.7	15,878.1	101.5
Average	15,549.7	0	− 8	15,541.7	15,931.6	102.5
Period 3:						
First day	10,831.0	+ 54	− 75	10,810.0	11,420.8	105.6
Second day	10,842.6	+ 54	+ 25	10,921.6	11,419.6	104.6
Average	10,836.8	+ 54	− 25	10,865.8	11,420.2	105.1
Period 2:						
First day	9,659.3	+ 16	− 32	9,643.3	9,909.6	102.8
Second day	9,444.2	+ 16	− 9	9,451.2	9,763.0	103.3
Average	9,551.8	+ 16	− 21	9,546.8	9,836.3	103.0
Period 4:						
First day	7,989.9	+ 57	− 2	8,044.9	8,264.9	102.7
Second day	7,964.9	+ 57	− 26	7,995.9	8,107.8	101.4
Average	7,977.4	+ 57	− 14	8,020.4	8,186.4	102.0

[a] Assuming the correction for 48 hours (Table 7) to be equally divided between the two days.

SOIL FACTORS AFFECTING THE TOXICITY OF ALKALI

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INTRODUCTION

In alkali studies carried out at the Utah Experiment Station during a number of years, variations in toxicity under different conditions have been very evident. This has already been reported by one of us,[1] in results wherein the various alkali salts and particularly the carbonates were injurious in lower concentrations in sand than in loam. Other soil factors were also found to influence the action of soluble salts on plants. In order to gain more information regarding these factors, the investigations herein reported were undertaken, since it was realized that no adequate idea of the alkali problem could be had without an understanding of the factors involved.

Millions of acres of land in the arid part of America contain certain soluble salts in sufficient concentration to interfere with the best growth of crops. The value of much of this land is uncertain, since the salt content is near the concentration that renders it worthless. It is important, therefore, to know as nearly as possible just what the critical concentrations are. Hilgard and other early investigators contributed much to our knowledge of alkali lands, but their investigations did not make clear all the factors involved. This work is an attempt to determine with more exactness the quantities of the various salts that prohibit crop growth under different soil conditions.

The earlier paper[1] reviews the important literature on the subject; consequently no literature is reported in the present paper.

METHODS OF EXPERIMENTATION

The first method used was the direct empirical experiment of growing crops in prepared alkali soils in glass tumblers. Over 12,000 tumblers were planted in this experiment. The general method of procedure was exactly the same as was used previously[2] in studying the effect of different salts and combinations of salts. The tumblers were made to a uniform weight by placing washed gravel in the bottom. Two hundred gms. of soil, to which the salts had been added in solution as required in the experiment, were placed in each tumbler, and 10 kernels of New Zealand wheat planted in each. Daily notes were taken on the number of plants up in each tumbler and on any other observable data. The

[1] HARRIS, F. S. EFFECT OF ALKALI SALTS IN SOILS ON THE GERMINATION AND GROWTH OF CROPS. *In* Jour. Agr. Research, v. 5, no. 1, p. 1-53, 48 fig. 1915. Literature cited, p. 52-53.

[2] HARRIS, F. S. OP CIT.

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tumblers were made up to weight with distilled water as often as the loss became appreciable. On the twenty-first day after planting, the crop was harvested by cutting the plants at the surface of the ground with small scissors. The height of each plant and the number of leaves were

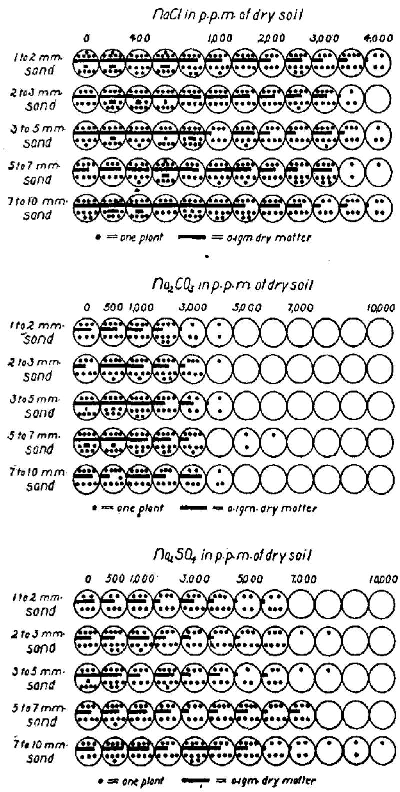

FIG. 1.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in quartz sand of different sizes containing sodium chlorid. Sodium carbonate and sodium sulphate added in various concentrations. Moisture content maintained at 20 per cent throughout.

recorded. The plants from each tumbler were placed in an envelope and dried in an oven, and the dry weight was determined. The 3-week period was arbitrarily chosen, because by that time nearly all the plants that would germinate had done so, and the growth ceased to be vigorous.

It was found that the dry weight at harvest gave the best figures for comparison. The number of plants germinated, the average number of days required to germinate, the average height of plants, and the aver-

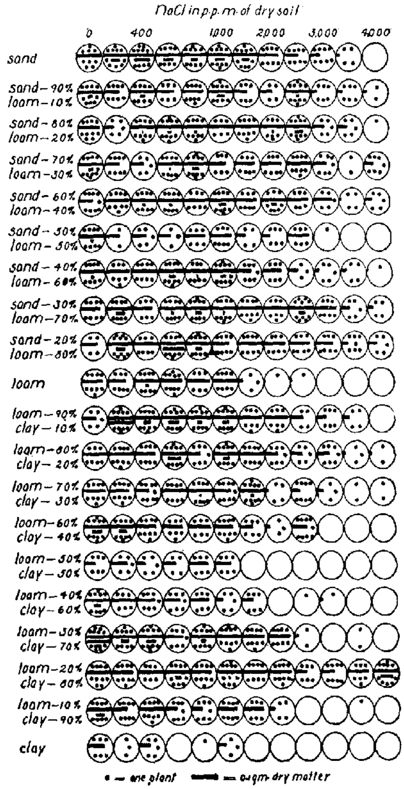

FIG. 2.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils of different texture containing sodium chlorid added in various concentrations. Moisture content maintained at 20 per cent throughout.

age number of leaves were also used as indicators of plants growth. In these experiments only the three most important alkali salts, sodium chlorid, sodium carbonate, and sodium sulphate, were used. The relative toxicity of most of the alkali salts was reported in the earlier paper.

EFFECT OF SIZE OF SOIL PARTICLES

The first factor to be examined was the effect of the size of soil particles on the toxicity of alkali. For this purpose pure quartz sand graded into five sizes was used. The experiment was repeated three times in

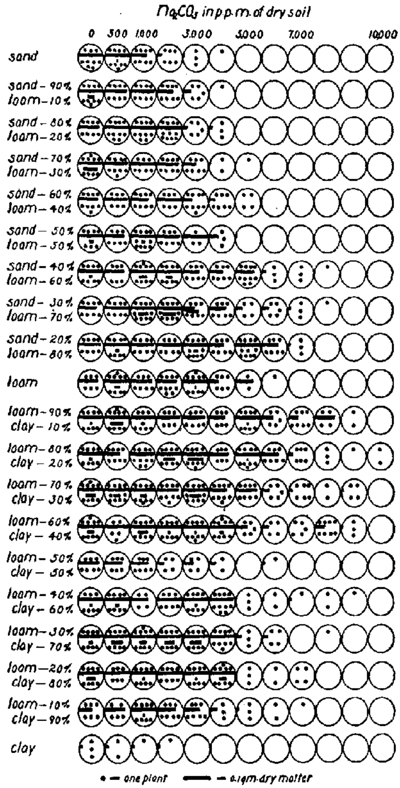

FIG. 3.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils of different texture containing sodium carbonate added in various concentrations. Moisture content maintained at 20 per cent throughout.

two different years, twice at 20 per cent moisture and once at 10 per cent. The details of the make-up of the tumblers and the results are shown in figure 1.

The size of particles alone, as shown by the quartz sand, seemed to have no appreciable effect on the toxicity of the salts. The different moisture content shows a marked difference here as elsewhere. The results with sand are the only ones showing the carbonate more toxic than the chlorid on the basis of the amount of salt added.

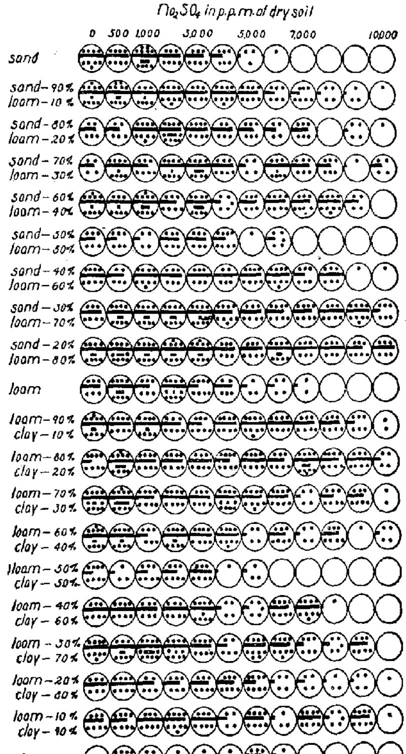

FIG. 4.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils of different texture containing sodium sulphate added in various concentrations. Moisture content maintained at 20 per cent throughout.

As a continuation of the study of the effect of size of particles or texture, various combinations were used, including soils varying from sand through loam to a brickyard clay. The loam contained more organic matter than either of the others. This condition is usually found in

natural soils. A series was conducted with local sand, Greenville loam, and clay, and mixtures of half and half of these. Later, another series was conducted using more grades of mixtures. Owing probably to weather conditions, the second series grew better as a whole than the

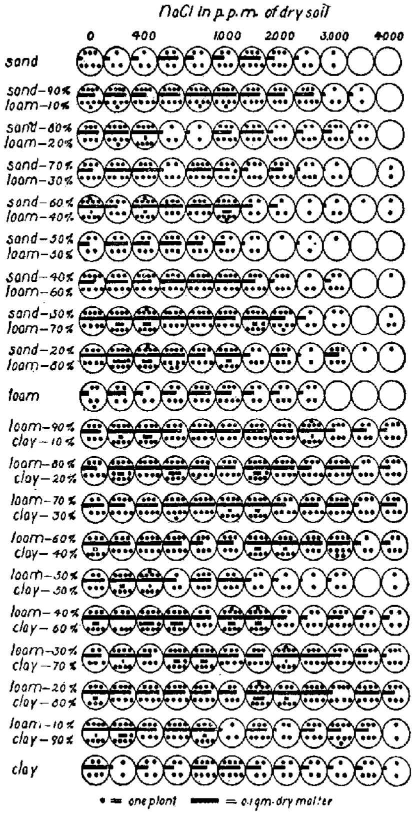

FIG. 5.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils containing sodium chlorid added in various concentrations. Soils maintained at an equivalent moisture content.

first; but, since the figures are equally distributed, they can be placed in one table for study. All soil was maintained at 20 per cent moisture on the basis of the dry soil. The details of the experiment and the results are shown in figures 2, 3, and 4. It is noticeable from the figures that

the loam is more tolerant than either of the extremes and that the lighter loam soils are more tolerant than the heavier. This is especially noticeable with the carbonates.

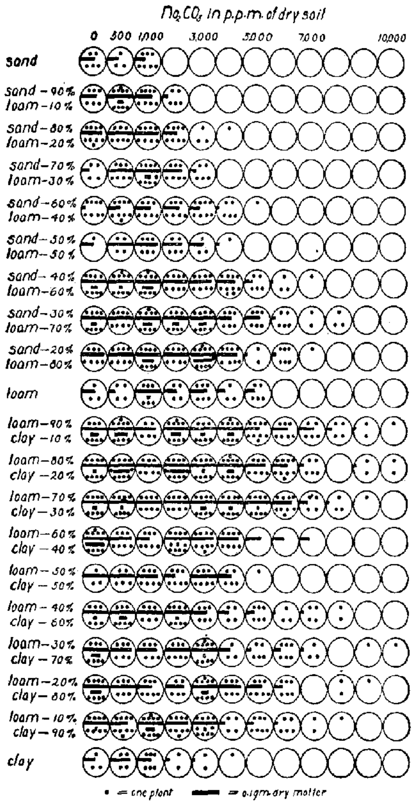

FIG. 6.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils of different texture containing sodium carbonate added in various concentrations. Soils maintained at an equivalent moisture content.

It was noticed in this experiment that at 20 per cent moisture content the sand was nearly saturated, while the clay was comparatively dry. In order to overcome the effect of the varying moisture relations when soils of all textures were maintained at 20 per cent, experiments were

conducted with the soils as nearly as possible to an equivalent moisture content or the same relative degree of wetness. Since there was no centrifuge available, this equivalent moisture content was determined by

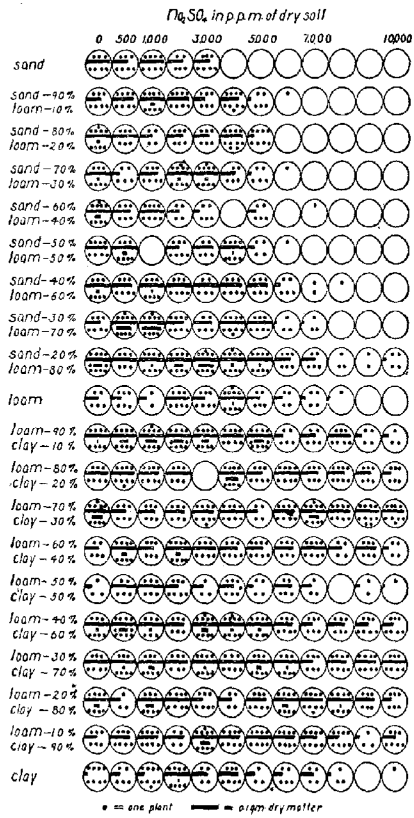

FIG. 7.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in soils of different texture containing sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

placing the soils at various moisture contents in contact with loam at 20 per cent moisture in sealed vessels and observing by the moisture movements the percentage in each case which was in equilibrium with 20 per cent in the loam.

As determined by several duplicates of this method, 10 per cent moisture in the sand, 27 per cent in the clay, and 50 per cent in peat,

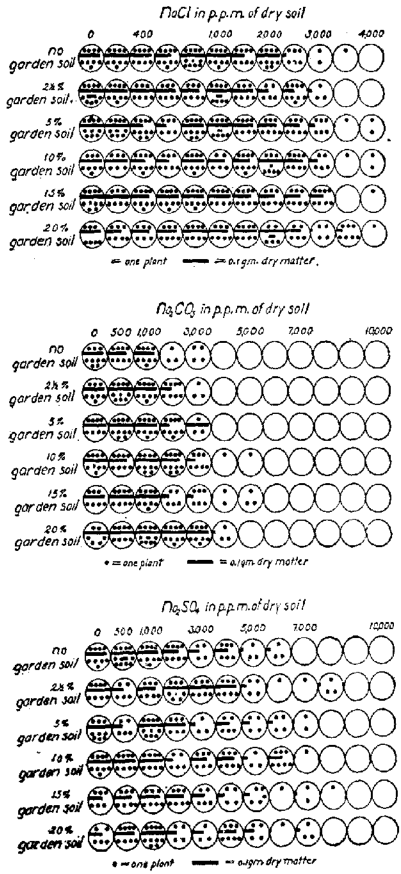

FIG. 8.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand with different amounts of garden soil containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Moisture content maintained at 20 per cent throughout.

used in later experiments, was found to be equivalent to 20 per cent in the loam. As worked out later on the moisture-equivalent centrifuge,

the equivalents were sand 2.66 per cent, loam 23.92 per cent, clay 27.07 per cent, and peat 51.80 per cent; but the first results are probably as

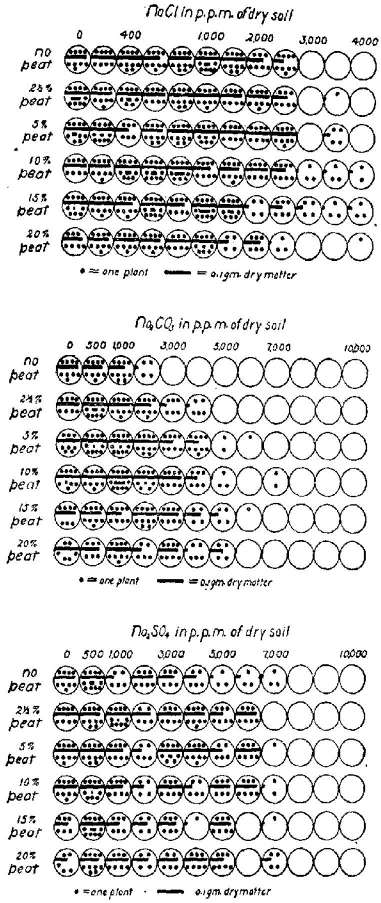

FIG. 9.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand with different amounts of peat containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Moisture content maintained at 20 per cent throughout.

satisfactory for this experiment, since the sand at the lower moisture content would be unworkable. The results of this experiment are

shown in figures 5, 6, and 7. These graphs show but little difference in the tolerance of sand and clay, but the presence of loam greatly increases tolerance for alkali.

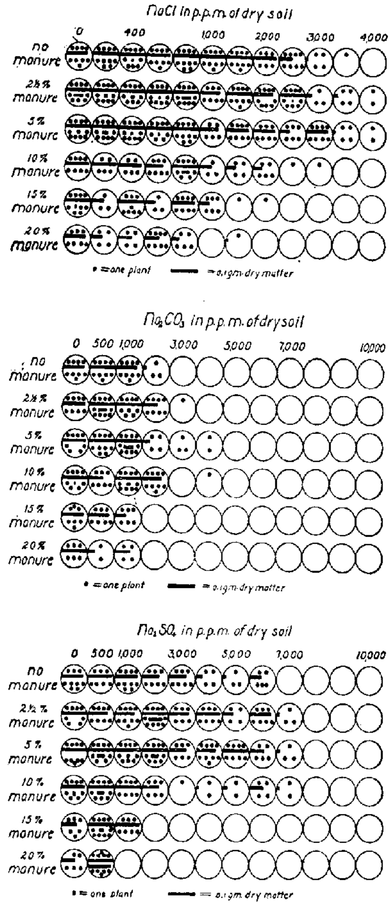

FIG. 10.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand with different amounts of manure containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Moisture content maintained at 20 per cent throughout.

In order to eliminate the effect of the organic matter which was present in the loam and not in the other soils, two series were conducted,

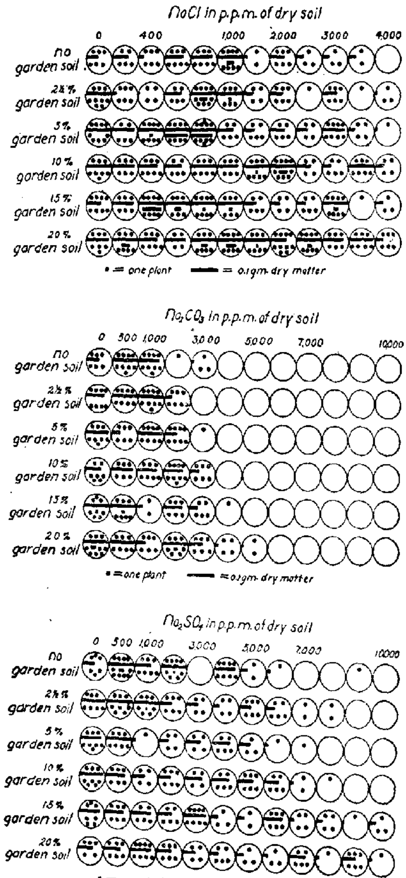

FIG. 11.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand with different amounts of garden soil containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

using only mixtures of clay and sand at an equivalent moisture content. In one series no organic matter was added, and in the other 10 per cent

of sifted peat was added to each. In this case only four concentrations of the salt were used and there were four duplicates of each treatment.

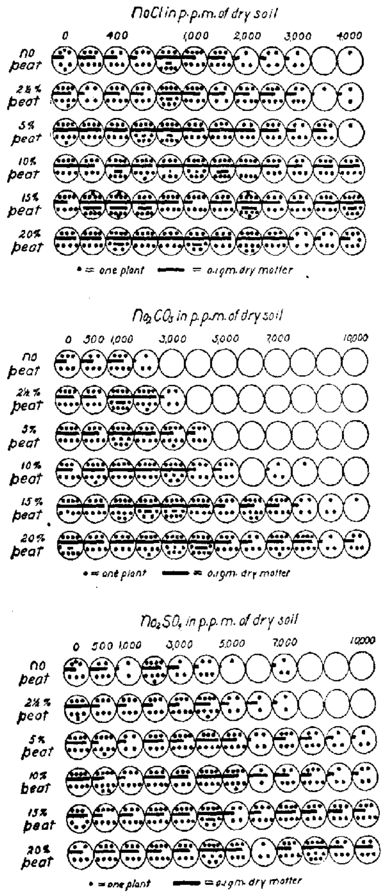

FIG. 12.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand with different amounts of peat containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

These were averaged. The results are given in Tables I and II. These tables show that without the organic matter the heavier soils are more

tolerant at the equivalent moisture content; but with the organic matter added, which greatly increased the equivalent moisture, there is no

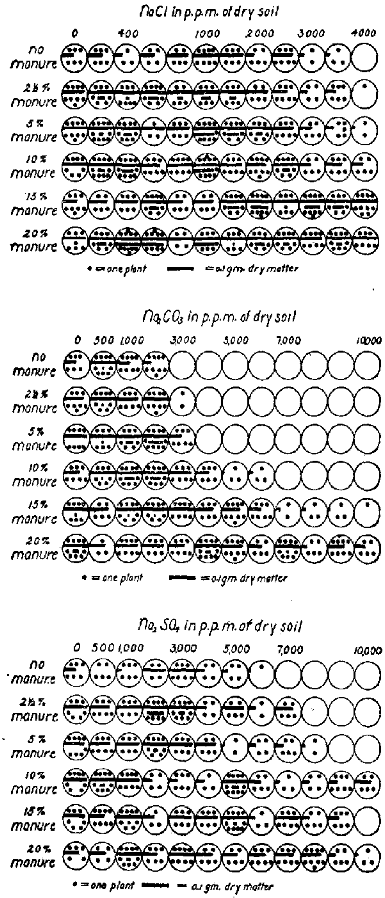

FIG. 13.—Diagram showing the number of wheat plants up and the dry matter produced in sand with different amounts of manure containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils manintained at an equivalent moisture content.

appreciable effect. All these results considered together seem to indicate that loams are more tolerant than sands or clays, and that at the same

moisture content the lighter loams are more tolerant; but if enough more water is added to make them equally wet the heavier soils are more tolerant.

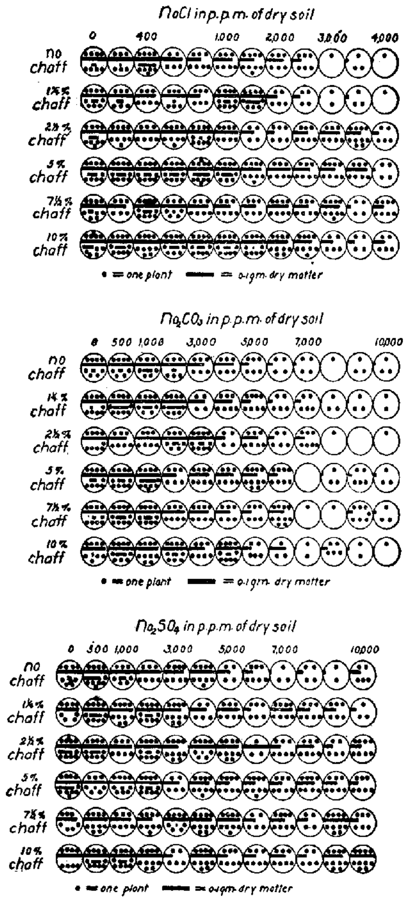

FIG. 14.—Diagram showing the number of wheat plants up and the dry matter produced in loam with different amounts of chaff, containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

TABLE I.—*Average dry matter of wheat (in 0.0001 gm.) produced in 21 days in sand and clay mixtures, with no organic matter and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations. Soils maintained at an equivalent moisture content*

Salt and concentration.	Sand.	Sand 90, clay 10.	Sand 80, clay 20.	Sand 70, clay 30.	Sand 60, clay 40.	Sand 50, clay 50.	Sand 40, clay 60.	Sand 30, clay 70.	Sand 20, clay 80.	Sand 10, clay 90.	Clay.	Average.
P. p. m.												
Control	1,195	1,321	1,156	1,244	1,086	1,188	1,174	1,063	1,190	788	740	1,104
SODIUM CHLORID.												
1,000	1,201	643	669	578	858	917	1,264	775	687	778	1,325	881
2,000	38	7	58	161	608	367	786	318	427	484	918	379
3,000	......	......	......	......	......	55	43	127	323	367	500	129
4,000	......	......	......	......	......	......	1	25	88	7	479	55
Average	310	162	182	185	367	335	524	311	381	409	805	361
SODIUM CARBONATE.												
2,000	215	5	89	97	142	439	644	972	764	906	1,217	499
4,000	......	......	......	......	8	134	18	241	581	436	542	178
6,000	......	......	......	......	......	9	49	11	41	216	472	72
8,000	......	......	......	......	......	......	......	57	9	46	142	23
Average	54	1	22	24	38	161	178	320	349	401	593	194
SODIUM SULPHATE.												
3,000	382	259	651	1,009	518	1,189	199	976	1,082	1,118	1,159	787
6,000	......	......	......	5	......	88	10	182	199	178	558	111
9,000	......	......	......	......	......	......	......	......	1	18	18	4
12,000	......	......	......	......	......	......	......	......	......	......	......	0
Average	95	65	190	255	130	319	52	290	321	329	434	225

TABLE II.—*Average dry matter of wheat (in 0.0001 gm.) produced in 21 days in sand and clay mixtures with 10 per cent peat and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations. Soils maintained at an equivalent moisture content*

Salt and concentration.	Sand.	Sand 90, clay 10.	Sand 80, clay 20.	Sand 70, clay 30.	Sand 60, clay 40.	Sand 50, clay 50.	Sand 40, clay 60.	Sand 30, clay 70.	Sand 20, clay 80.	Sand 10, clay 90.	Clay.	Average.
P. p. m.												
Control	1,073	1,084	943	839	778	1,040	566	653	661	535	864	821
SODIUM CHLORID.												
1,000	1,409	1,053	1,202	1,294	1,305	935	1,501	1,162	1,435	1,039	1,089	1,220
2,000	873	898	1,244	1,280	920	945	975	622	1,192	818	764	957
3,000	272	422	732	529	294	603	684	671	589	646	320	524
4,000	159	125	175	145	64	380	401	278	474	204	202	237
Average	678	625	838	812	646	716	890	683	922	677	594	734
SODIUM CARBONATE.												
2,000	1,070	939	1,328	1,079	1,520	1,094	1,042	374	780	......	511	974
4,000	1,188	533	931	1,141	1,554	888	750	478	796	......	558	862
6,000	592	515	889	841	898	874	603	700	717	......	350	698
8,000	149	157	192	455	586	425	460	673	434	......	268	380
Average	750	536	835	879	1,140	820	714	556	682	......	422	734
SODIUM SULPHATE.												
3,000	1,313	1,442	1,083	1,407	1,120	1,156	998	1,002	914	1,218	1,382	1,185
6,000	1,178	1,161	1,152	1,023	1,264	1,191	908	1,255	1,117	1,059	1,000	1,119
9,000	1,077	1,088	1,140	1,070	913	966	703	739	656	725	521	873
12,000	883	873	807	803	800	694	596	761	467	758	712	741
Average	1,113	1,141	1,046	1,076	1,024	1,002	801	939	789	940	904	979

EFFECT OF ORGANIC MATTER

Another factor to be studied separately was the effect of the organic matter of the soil on the toxicity of the alkali. The results given above

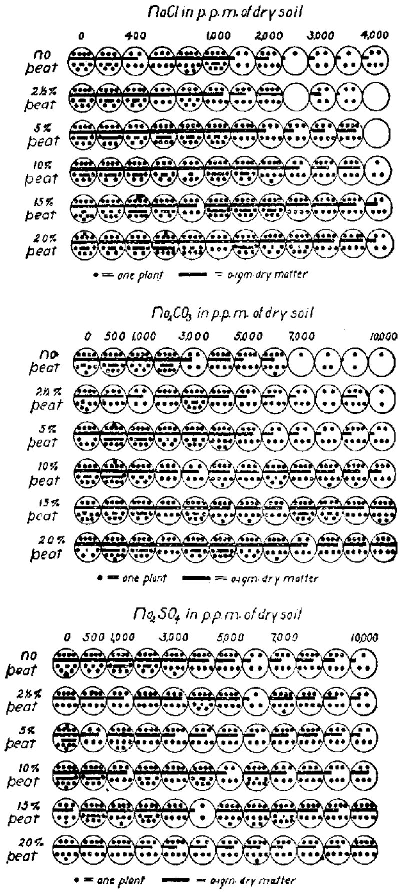

FIG. 15.—Diagram showing the number of heat plants up and the dry matter produced in loam with different amounts of peat containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

seem to indicate quite strikingly that organic matter increases tolerance. Several series of experiments were conducted to show the effect of a rich

garden soil, sifted peat, and sifted manure in varying quantities on the toxicity of alkali in sand at the same and at equivalent moisture con-

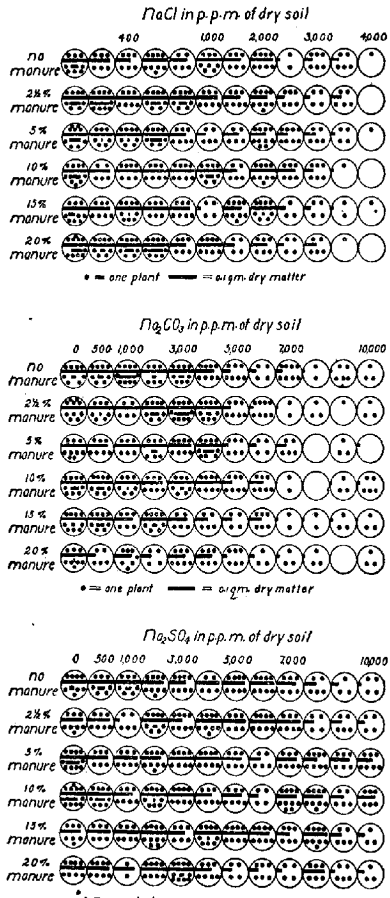

FIG. 16.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in loam with different amounts of manure containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations. Soils maintained at an equivalent moisture content.

tents and of fresh chaff, peat, and manure on loam. The peat used was a rotted woody and leafy material deposited by Logan River The manure was fairly well rotted. The results are shown in figures 8 to 16.

Additional organic matter seemed to increase the tolerance of the soil for alkali if enough additional water was added to bring it up to an equivalent moisture content, but increased the toxicity if the extra

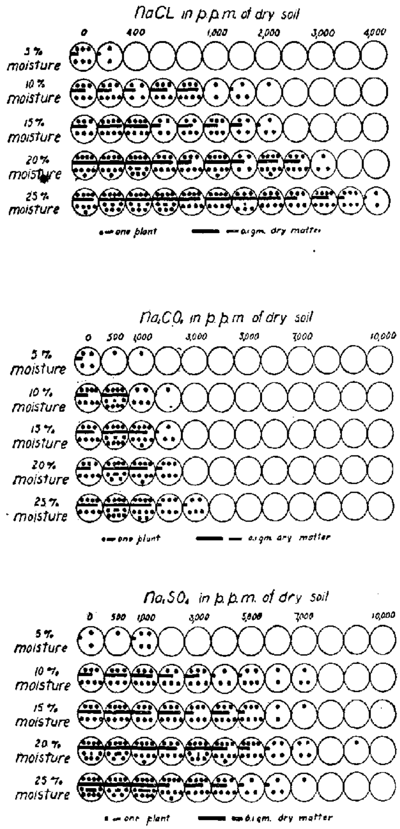

FIG. 17.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

moisture was not added. The greatest effect was produced by the peat probably because it was the finest and could be most thoroughly incorporated into the soil. The results were more noticeable in the case of the carbonates than in that of the two other salts.

EFFECT OF MOISTURE CONTENT

In order to test more completely the effect of different moisture contents on the toxicity of the alkali salts, a separate series of experiments was conducted using many of the soils used in the other experiments at different moisture contents. These varied between the lowest and highest extremes at which seeds could be made to germinate.

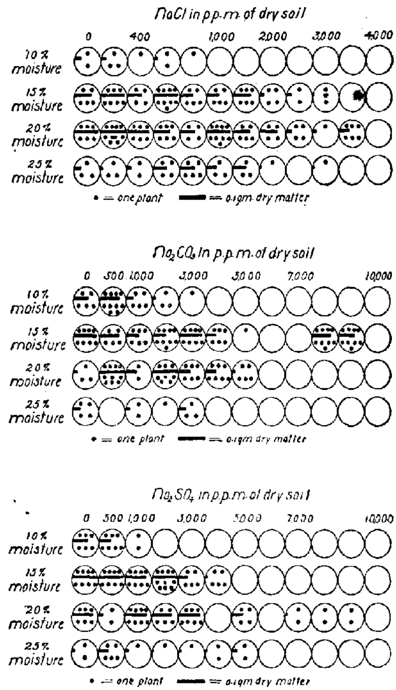

FIG. 18.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand and loam maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

The results which are given in figures 17 to 26 show that the resistance was increased with the increased moisture content up to the point of excessive moisture for plant growth. This was the most noticeable correlation observed in all these investigations. Two additional series were conducted on the plan of duplicating tumblers and using only four concentrations. In the first, the salt content of each set was the same

on the basis of the dry soil, but the moisture content varied. In the second, the soils were made up with different amounts of the same solution, the concentration being maintained by adding water as it was lost

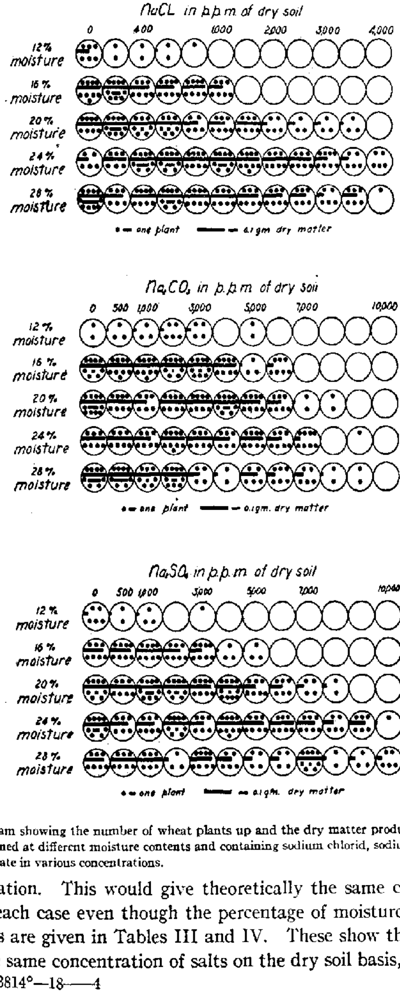

FIG. 19.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in loam maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations.

by evaporation. This would give theoretically the same concentration of salt in each case even though the percentage of moisture was varied. The results are given in Tables III and IV. These show that with soils having the same concentration of salts on the dry soil basis, the greatest

resistance was found at the highest moisture content consistent with good growth. In the second series, in which the theoretical concentration of the soil solution was the same, different results were observed. In the case of the chlorids and sulphates the toxicity was nearly proportional to the strength of the solution, the best growth otherwise being with the optimum moisture content. In the case of the carbonates, however, the

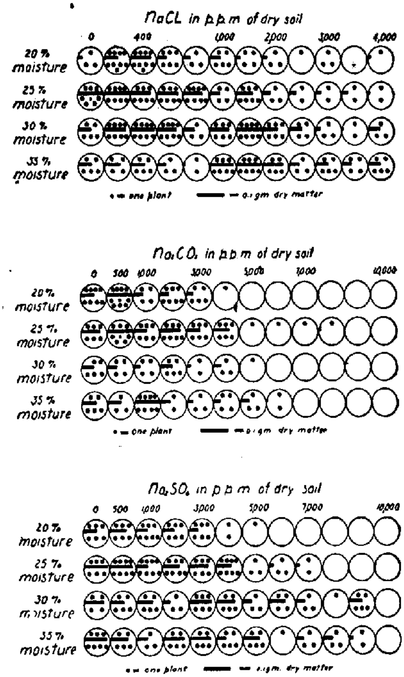

FIG. 20.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in loam and clay maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

greatest growth was where the least amount of solution, and consequently of salt, had been applied. This shows that in the case of the carbonates at least the concentration of the soil solution does not depend directly on the proportion of salt to soil, or on the proportion of salt to water, but on a combination of all these factors probably, depending on the relative absorptive powers of the soil for the salt and for water.

TABLE III.—*Average dry matter (in 0.0001 gm.) produced in loam soil maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations based on the dry weight of the soil*

Salt and concentration.	Dry matter produced.										Average.
Moisture in soil ....per cent..	12	14	16	18	20	22	24	26	28	30	
P. p. m.											
Control...............	300	866	1,222	1,315	1,383	1,489	1,190	1,502	1,241	1,049	1,156
SODIUM CHLORID.											
1,000..................	......	595	521	1,218	1,143	1,186	1,368	1,260	782	737	881
2,000..................	......	......	17	168	575	843	1,083	1,070	891	563	521
3,000..................	......	......	......	38	32	96	279	468	503	464	188
4,000..................	......	......	......	......	1	73	175	301	435	299	128
Average.........	......	149	135	356	438	550	731	775	653	513	430
SODIUM CARBONATE.											
2,000..................	......	343	752	1,087	1,013	992	1,069	965	927	624	777
4,000..................	......	220	627	823	930	1,014	878	813	968	740	701
6,000..................	......	......	17	29	76	229	347	412	356	135	160
8,000..................	......	......	......	......	1	28	34	64	80	22	23
Average.........	......	141	349	485	505	566	582	563	583	380	415
SODIUM SULPHATE.											
3,000..................	......	77	245	808	806	1,141	1,261	918	722	843	682
6,000..................	......	......	9	56	504	265	709	1,049	948	359	390
9,000..................	......	......	......	......	......	2	50	108	185	42	39
12,000..................	......	......	......	......	......	......	......	......	11	32	4
Average.........	......	19	64	216	328	352	505	519	467	319	279

TABLE IV.—*Average dry matter (in 0.0001 gm.) produced in loam soil maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations based on the theoretical strength of the soil solution*

Salt and concentration.	Dry matter produced.										Average.
Moisture in soil ....per cent..	12	14	16	18	20	22	24	26	28	30	
P. p. m.											
Control...............	1,255	1,040	1,125	1,012	991	1,231	1,155	842	914	655	1,022
SODIUM CHLORID.											
5,000..................	652	908	903	943	1,191	1,190	927	764	697	129	830
10,000..................	299	706	1,033	1,007	925	1,095	908	821	464	12	727
15,000..................	251	389	558	618	610	737	899	523	554	292	543
20,000..................	313	281	196	292	173	131	259	322	311	112	239
Average.........	379	571	673	715	725	788	757	608	507	136	585
SODIUM CARBONATE.											
10,000..................	645	1,092	1,100	930	816	938	897	720	584	257	798
20,000..................	775	1,084	938	678	768	613	895	872	376	320	732
30,000..................	659	805	944	870	749	736	450	132	22	1	537
40,000..................	611	565	465	148	158	82	10	......	......	......	204
Average.........	673	886	862	657	623	592	563	431	237	145	568
SODIUM SULPHATE.											
15,000..................	582	907	1,147	1,130	1,324	1,335	1,356	1,350	683	148	996
30,000..................	595	582	740	813	1,109	1,060	1,218	1,453	969	753	929
45,000..................	212	276	611	469	825	383	544	558	258	146	429
60,000..................	24	150	75	108	104	81	28	43	44	12	67
Average.........	355	479	643	630	840	715	787	851	488	265	605

EFFECT OF ADDED SALTS ON CONCENTRATION OF SOIL SOLUTION

In order to get some definite conclusions as to the actual concentration of the soil solution in these alkali soils under the conditions of the experi-

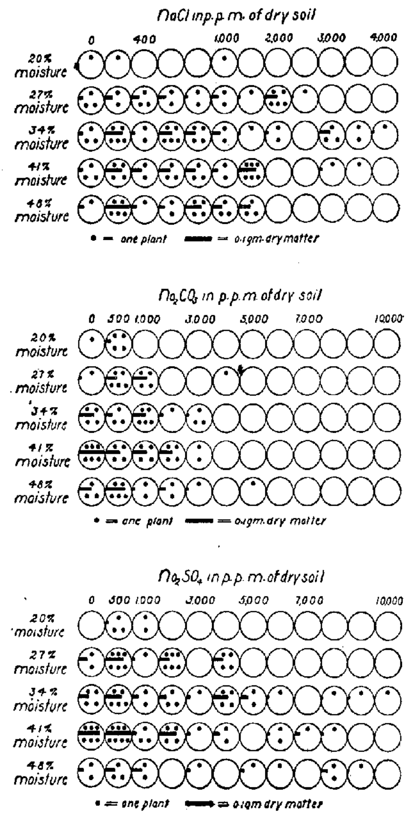

FIG. 21.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in clay maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

ment, the freezing-point method described by Bouyoucos and McCool[1] was used. The soils were dried and later made up to the moisture content

[1] BOUYOUCOS, G. J. and McCOOL, M. M. THE FREEZING-POINT METHOD AS A NEW MEANS OF MEASURING THE CONCENTRATION OF THE SOIL SOLUTION DIRECTLY IN THE SOIL. Mich. Agr. Exp. Sta. Tech. Bul. 24, p. 592–631 2 fig. 1916.

used in the experiment. They were left standing in stoppered containers for forty-eight hours. It was found that no regular results could be obtained without this forty-eight-hour period of standing. The freezing point was then determined by the method referred to above. From solution experiments it was found that a gram-molecular solution of sodium chlorid froze at $-3.56°$ C., sodium carbonate at $-4.58°$ C.,

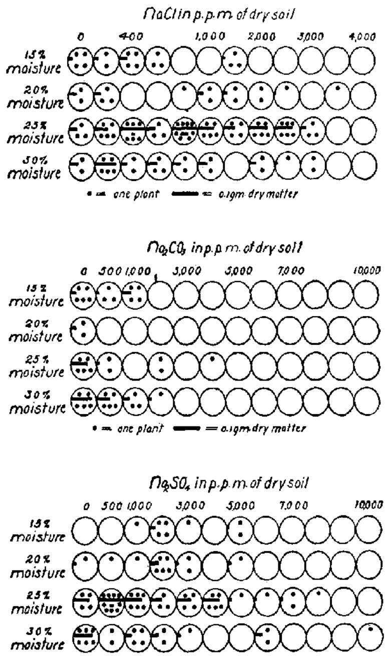

FIG. 22.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand and clay maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations.

and sodium sulphate at $-4.37°$ C., the depression being directly proportional to the concentration. With these figures it was possible to calculate additional strength of the soil solution from the freezing point, assuming it contained only the salt added. From this and the theoretical strength, calculated from the amount of salt and water added, the relative adsorption of salt and of water could be calculated. It was found necessary to use a check with each series for comparison, since some

unknown factor caused a variation in all samples from day to day, but on each day the relation between the check and the treatment was consistent. It was found that the depression of the freezing point varies consistently with the concentration and that duplicate samples checked to

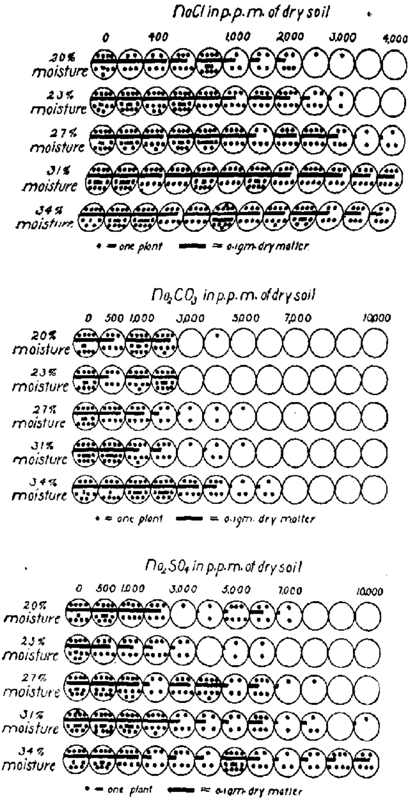

FIG. 13.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand and clay maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations.

within 0.01 or 0.02 degree. The freezing point of soils used in preparing figures 2, 3, and 4 was taken, and the results were averaged for the different content of each salt and for the different types of soil. The results are given in Tables V, VI, and VII, which show the quantity of the salt

added and the quantity that was determined by the freezing-point method to be actually in the soil solution. In the case of the added sodium chlorid it was noticeable that there is more salt shown than was added, which indicates either that there was more water than salt adsorbed by

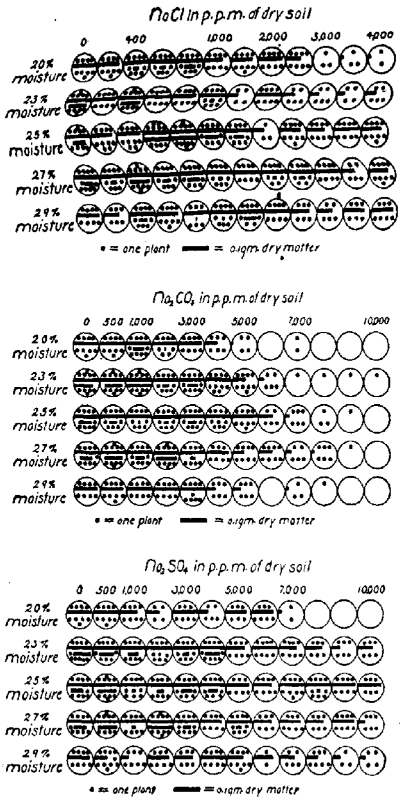

FIG. 24.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in sand and peat maintained at different concentrations and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

the soil or that other substances were brought into solution from the soil by adding the sodium chlorid. This effect reached a maximum at 2,500 p. p. m. of salt. There was no regular difference with the different soil types. In the case of the sulphates, apparently not all of the salt remained in solution except in the lowest concentrations. This was to

be expected from the large amount of the crystalline salt that appeared at the surface of the tumblers of higher concentration. The sodium carbonate shows the most interesting results. Over 80 per cent of the lowest concentration (500 p. p. m.) has disappeared from the solution, so far as its effect on the freezing point is concerned. It is also noticeable that the greatest adsorption occurred in the soils having the greatest amount of organic matter as was to be expected from our other results. The amount of the salt that could be detected in these soils by the ordinary method of water extraction and titration is shown in Table VIII, for comparison. The results agree remarkably well. This seems to show that the organic matter in the soil not only neutralizes the basicity of the carbonate but actually removes it from the solution altogether.

TABLE V.—*The increase in the concentration of the soil solution by adding sodium chlorid in various quantities to different soils. Increase in concentration determined by the depression of the freezing point and expressed as parts per million of sodium chlorid in dry soil*

Soil.	Concentration.											Average.
Salt added . . p. p. m.	200	400	600	800	1,000	1,500	2,000	2,500	3,000	3,500	4,000	
Sand 90, loam 10 . . .	231	560	889	1,251	1,844	2,865	3,886	5,302	6,389	8,662	8,958	3.712
Sand 80, loam 20 . . .	527	650	1,284	1,515	1,844	2,569	4,677	6,224	6,587	6,916	9,090	3.808
Sand 70, loam 30 . . .	99	856	1,120	1,284	1,844	2,601	3,359	3,491	5,730	6,488	5,269	2,922
Sand 60, loam 40 . . .	33	296	626	1,087	1,219	2,009	3,425	4,446	5,072	6,225	7,443	2,898
Sand 40, loam 60 . . .	395	650	790	1,021	2,437	2,470	3,326	3,952	4,512	5,105	5,368	2,730
Sand 30, loam 70 . . .	263	593	725	988	1,251	1,976	2,734	3,195	4,150	4,742	5,269	2,353
Sand 20, loam 80 . . .	231	560	650	1,087	1,284	1,844	2,668	3,326	3,557	4,380	5,171	2,251
Loam 90, clay 10 . . .	33	132	461	692	889	1,614	2,569	2,832	3,293	3,820	4,183	1,865
Loam 80, clay 20	231	428	428	560	955	1,647	2,075	2,602	3,195	3,425	4,380	1.811
Loam 70, clay 30 . . .	66	231	494	692	757	1,284	1,482	2,075	2,700	3,557	3,655	1.545
Loam 60, clay 40 . . .	33	165	362	494	922	1,350	1,811	2,437	2,964	3,293	3,985	1,620
Loam 40, clay 60 . . .	132	296	296	659	955	1,515	2,470	2,799	3,063	3,853	4.084	1,829
Loam 30, clay 70 . . .	165	395	527	889	988	1,482	1,811	2,437	3,030	3,557	3,623	1.719
Loam 20, clay 80 . . .	33	132	362	659	790	1,416	2,042	1,943	3,260	3,293	2,668	1,599
Loam 10, clay 90 . . .	395	626	790	922	1,284	1,581	2,305	2,898	3,656	3,491	4,018	1.997
Average	191	438	654	920	1,284	1,881	2,709	3,331	4,077	4,720	5,149	. . . . . .

TABLE VI.—*The increase in the concentration of the soil solution by adding sodium carbonate in various quantities to different soils. Increase in concentration determined by the depression of the freezing point and expressed as parts per million of sodium carbonate in dry soil*

Soil.	Concentration.											Average.
Salt added . . p. p. m.	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	
Sand 90, loam 10 . . .	93	1,072	1,864	3,262	5,685	6,852	9,361	9,600	12,256	12,256	13,514	6,892
Sand 80, loam 20 . . .	47	280	699	1,869	3,500	5,219	5,965	8,947	10,019	10,205	10,347	5,190
Sand 70, loam 30 . . .	47	559	559	1,481	3,122	3,821	4,707	6,990	8,901	9,273	10,066	4,503
Sand 60, loam 40 . . .	47	186	652	932	1,911	2,886	3,821	4,613	6,291	8,295	9,413	3,549
Sand 40, loam 60 . . .	93	233	470	839	1,198	1,455	2,470	3,776	6,291	6,617	4,893	2,576
Sand 30, loam 70 . . .	. . . . . .	186	470	419	792	1,222	1,771	2,982	3,821	4,660	5,312	1,966
Sand 20, loam 80 . . .	140	233	419	470	700	1,165	1,548	2,145	2,237	4,339	3,961	1,578
Loam 90, clay 10 . . .	93	140	140	373	608	841	1,128	1,491	2,050	2,516	2,936	1,119
Loam 80, clay 20 . . .	93	186	280	513	932	1,165	1,455	1,820	2,097	2,330	3,309	1,289
Loam 70, clay 30 . . .	140	93	280	513	756	932	1,035	1,400	1,864	2,610	3,375	1,182
Loam 60, clay 40 . . .	93	280	326	559	652	652	1,175	1,165	1,631	1,957	2,703	1,018
Loam 40, clay 60 . . .	180	280	373	280	1,035	1,165	1,072	1,675	2,843	2,936	3,635	1,407
Loam 30, clay 70 . . .	93	140	140	326	932	1,496	1,864	1,864	2,703	2,283	2,843	1,335
Loam 20, clay 80 . . .	93	47	280	280	513	746	1,072	1,584	1,864	2,050	2,843	1,034
Loam 10, clay 90 . . .	280	513	559	373	1,584	1,491	1,911	2,843	2,796	3,914	4,820	1,889
Average	102	295	501	832	1,595	2,074	2,690	3,526	4,511	5,082	5,578	. . . . . .

TABLE VII.—*The increase in the concentration of the soil solution by adding sodium sulphate in various quantities to different soils. Increase in concentration determined by the depression of the freezing point and expressed as parts per million of sodium sulphate in dry soil*

Soil.	Concentration.											Average.
Salt added..p.p.m.	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	
Sand 80, loam 20...	1,306	2,090	3,985	6,663	8,492	9,863	8,884	9,602	7,838	7,773	8,034	6,775
Sand 70, loam 30...	2,743	2,155	3,789	4,703	9,472	9,798	9,994	9,341	9,733	7,773	7,838	7,031
Sand 60, loam 40...	784	1,698	3,070	4,376	7,051	9,014	4,512	9,994	9,145	7,773	8,361	5,980
Sand 40, loam 60...	261	1,110	1,894	2,874	4,638	6,597	7,708	8,230	9,080	9,537	13,000	5,900
Sand 30, loam 70...	849	849	2,678	3,397	4,246	5,095	8,165	9,210	9,537	9,602	11,104	5,884
Sand 20, loam 80...	914	1,241	2,221	2,939	4,050	5,160	5,748	6,663	6,989	7,969	9,798	4,779
Loam 90, clay 10...	588	1,045	2,090	2,809	3,266	4,050	4,703	5,095	6,597	6,662	7,381	4,026
Loam 80, clay 20...	784	784	1,698	2,548	3,201	4,181	4,442	4,964	5,618	6,205	7,447	3,806
Loam 70, clay 30...	391	719	1,960	2,939	2,809	3,723	3,723	4,703	6,205	5,879	6,933	3,638
Loam 60, clay 40...	784	1,241	1,894	2,482	3,331	3,593	4,181	4,703	5,356	5,814	6,597	3,636
Loam 40, clay 60...	719	719	1,960	2,090	3,005	3,331	3,266	3,789	5,160	5,291	6,140	3,224
Loam 30, clay 70...	849	1,306	1,829	2,678	3,005	3,397	3,985	4,311	5,552	5,618	6,597	3,557
Loam 20, clay 80...	849	784	980	1,502	1,829	2,678	3,331	3,593	3,984	4,442	5,291	2,660
Loam 10, clay 90...	2,613	2,613	1,045	1,894	1,960	2,678	3,919	4,115	4,246	5,878	5,879	3,349
Average......	1,031	1,314	2,221	3,135	4,311	5,233	5,468	6,308	6,788	6,872	7,885	......

TABLE VIII.—*Amount of sodium carbonate that could be detected by water extraction in different soils to which it had been added in various quantities*

Soil.	Concentration.											Average.
Salt added..p.p.m.	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	
Sand 90, loam 10...	170	594	891	1,484	2,417	3,859	3,307	5,682	5,088	6,784	6,784	3,369
Sand 80, loam 20...	250	381	896	1,399	2,077	2,059	3,477	3,010	4,452	5,427	6,445	2,716
Sand 70, loam 30...	148	275	615	1,293	1,674	2,141	3,243	3,582	4,346	4,388	5,109	2,437
Sand 60, loam 40...	170	255	552	1,018	1,527	1,993	2,375	3,223	4,113	4,601	4,198	2,184
Sand 40, loam 60...	42	254	551	848	1,229	1,696	1,865	2,289	2,883	3,519	3,731	1,718
Sand 30, loam 70...	170	170	636	976	1,315	1,654	2,078	2,714	3,265	3,774	3,859	1,874
Sand 20, loam 80...	86	170	510	934	1,315	1,485	1,951	2,121	2,801	3,478	3,732	1,689
Loam 90, clay 10...	212	212	467	848	1,018	1,569	1,823	2,035	2,544	2,841	3,265	1,530
Loam 80, clay 20...	42	212	466	805	1,102	1,314	1,865	2,077	2,628	3,095	3,392	1,545
Loam 70, clay 30...	85	339	806	1,060	1,230	1,696	1,908	2,020	2,671	3,095	3,731	1,695
Loam 60, clay 40...	170	255	721	1,188	1,357	1,781	2,078	2,460	2,672	3,265	3,901	1,804
Loam 40, clay 60...	170	254	424	424	1,187	1,654	1,696	1,866	2,205	3,350	3,901	1,557
Loam 30, clay 70...	254	42	339	593	996	1,738	2,120	2,162	3,095	2,756	3,604	1,609
Loam 20, clay 80...	60	18	442	823	1,205	1,586	1,671	2,350	2,774	3,198	3,961	1,644
Loam 10, clay 90...	170	467	594	1,442	891	1,569	2,078	2,714	3,096	3,816	4,240	1,916
Average......	147	260	594	1,009	1,369	1,853	2,236	2,687	3,242	3,826	4,257	......

RELATIVE TOXICITY OF THE SALTS

Turning our attention to the relative toxicity of the three salts and averaging together the yields of dry matter from all tumblers in series having the same salt content, we obtain the results shown in figure 27, which shows the percentage of normal yield from all soil types and moisture contents for each concentration of each salt as added. It will be noticed that up to 1,000 p. p. m. all the salts are beneficial in the action, the carbonate being especially so. After 1,500 p. p. m. all the salts become increasingly toxic, the chlorid most so and the sulphate least, with the carbonate about halfway between.

Two very noticeable features of these results are that the chlorids average about twice as toxic as the carbonate on a basis of what was

added, and that there is notable discrepancy between the carbonate added to the soil and the amount as determined by water extraction. It would seem that these might to a certain extent be offered as a mutual

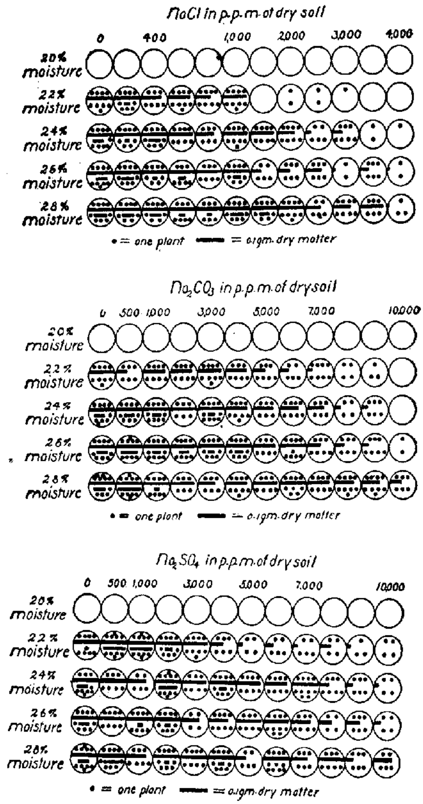

FIG. 25.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in loam and peat maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate added in various concentrations.

explanation of one another. Neither of these peculiarities was observed in our studies with sand.

Practically all of the results showing the carbonates to be more toxic than the chlorids have been obtained from studies in solutions and in sand cultures or from field studies where the salt has been determined

by water extractions. This extraction in experiments of this kind does not show all of the alkali carbonates that have been added. In averaging all the determinations it will be seen that less than half of the salt added was extracted. While this is not enough to change the results to the

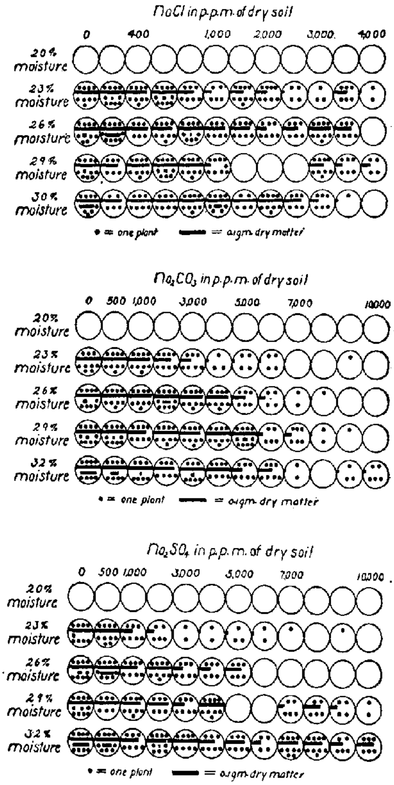

FIG. 26.—Diagram showing the number of wheat plants up and the dry matter produced in 21 days in loam and manure maintained at different moisture contents and containing sodium chlorid, sodium carbonate, and sodium sulphate in various concentrations.

customary statement that the carbonates are twice as toxic as the chlorids, it shows possibilities in this direction. The method of extracting was as follows: Fifty gm. of the oven-dry soil were added to 500 cc. of distilled water and stirred with a wooden paddle for five minutes. The

solution was allowed to settle for an hour and filtered through a Pasteur-Chamberland filter. Ten to fifty cc. of the clear solution were titrated with *N*/50 sulphuric acid, with methyl-orange as indicator and the results expressed as sodium carbonate. In cases where there was much organic matter in the soil the solution was very black, but by diluting with neutral water to a yellowish-brown color the end point could always be distinctly observed by one accustomed to making the titration. It was found that this method gave as nearly complete an extraction as

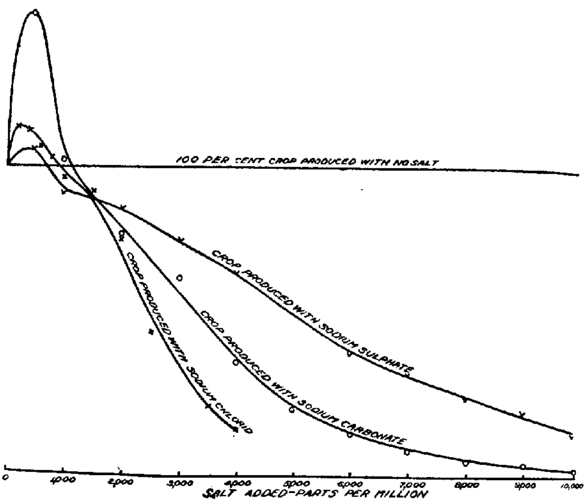

FIG. 27.—Graphs showing the percentage of normal yield of dry matter of wheat produced in 21 days with various concentrations of added sodium chlorid, sodium carbonate, and sodium sulphate. Average of all trials.

any method of cold-water extraction that we could find, but the solution was never complete. Since most field studies are made by water extractions, this may offer a partial explanation of the unusual nature of our results.

SUMMARY

(1) There is a great need for definite information regarding the toxicity of alkali salts in the soil.

(2) This paper reports about 12,000 determinations of the effect of alkali salts on plant germination and growth under different conditions.

(3) Size of particles of a sand independent of other factors does not seem appreciably to influence the toxicity of alkali.

(4) Loam soils are more tolerant of alkali than either sand or clay. The coarser loams are more tolerant than the finer at the same moisture content, but if the heavier loams are maintained at an equivalent moisture content they are more tolerant.

(5) Organic matter increases the resistance to alkali when the soil containing it is given sufficient moisture, but where present in large quantities organic matter decreases the resistance if the moisture supply is low.

(6) Increasing the moisture content of a soil up to the maximum that will produce good crops increases resistance to alkali.

(7) The toxicity of sodium chlorid and sodium sulphate seems to depend to quite an extent on the relation between concentration of salt and percentage of moisture present, while the toxicity of sodium carbonate is more largely affected by the presence of organic matter.

(8) Organic matter in the soil seems actually to remove sodium carbonate from the soil solution in large quantities.

(9) This probably explains why in experiments where sodium carbonate is added to a loam soil, it is less toxic than sodium chlorid, while in field studies where the salt is determined by analyses, and in solution and sand culture studies the sodium carbonate is more toxic.

Practical conclusions that may be drawn from these experiments are:

(1) Loam soils and soils with a high water-holding capacity may be successfully farmed at a higher alkali content than others.

(2) Soils in which alkali reduces crop yields should be kept as moist as is compatible with good plant growth.

(3) Manure, or other organic matter, should be beneficial to alkali soils, especially those high in carbonates.

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